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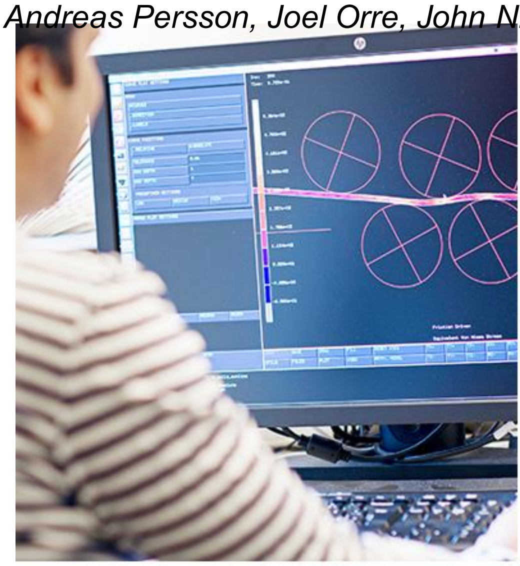
LITTERATURE STUDY FLEXIBLE HEATING

Andreas Persson, Joel Orre, John Niska, Mikael Larsson



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SUMMARY

The purpose of this literature study is find out the status of alternative fuels and methods for eliminate of the use of fossil fuels in steel reheating furnaces by the steel industry in order to become CO2 neutral by 2045. The goal of this initial investigation is to summarize the research front on oxyfuel combustion, hydrogen-biofuels, low calorific fuels and electrical heating. When it comes to hydrogen the literature study focus on production, usage and the future possibilities of integration into society across Europe. A comparative assessment on the environmental, energy efficiency and economical aspect is included.

CONTENT

1 INTRODUCTION

The Swedish government has proposed zero net tolerance against GHG emissions by 2045. To achieve this it is important not only to replace current fuels with renewable ones, but also use the excess energy efficiently to reduce unnecessary CO_2 emissions and increase the efficiency so that the amount of energy needed is as low as possible

Under normal production conditions there is a yearly production of 5Mton pig iron in Sweden. 35% of the produced steel comes from recycling and the rest is produced from ores. Both production routes require some kind of furnace, either for rolling or to get the wanted properties for the material. The metal industry stands for 10% of the total amount of GHG emissions in Sweden and 30% of the legal emission system. In 2015 the energy usage was 21.5TWh, where 7.4TWh comes from electricity and the rest from fossil based fuels. The mean emission from furnaces is 7.5% of the total steel industry and is varying between 5-50% depending on production route.

To increase the economics, securing a sustainable future and get environmental benefits, an increase in energy carriers with less CO_2 emissions or in electric-based energies is needed. Since both H_2 and O_2 can be produced from electricity there is a lot of potential in green electricity from the wind and sun, where excess energy can be used to heat furnaces. By shifting from fossil fuels to renewable fuel there will not only be less CO_2 emissions but also cheap electricity which the industry will benefit from.

2 ENERGY POLICIES

2.1 European policies

There currently exist three different goals within EU when it comes to renewable energy and greenhouse gases. The first target is 2020 [1] where EU is aiming to lower the greenhouse gas emission by at least 20% while increasing the share of renewable energy to at least 20% of the consumption and achieve 20% or more energy savings. Each country within EU must also achieve at least a 10% increase in the share of renewable energy within the transport sector. In order to achieve this EU has set out five priorities.

- Accelerate investments into efficient products, buildings and transport. Focus on renovation of public buildings and eco-design requirements for energy intensive products.
- By building a pan-European energy market from construction of the necessary transmission lines, LNG terminals, pipelines and other infrastructure, so that no country is isolated from the internal market.
- Protection of consumer rights by achieving high safety standards within the energy sector. It includes allowing consumers to easily switch energy suppliers, speedily resolve complaints and monitor energy usage.
- Implementation of the strategic energy technology plan - EU's strategy to accelerate development and deployment of low carbon technologies. The technologies include smart grids, solar power, capture and storage of carbon.
- Pursuing good relations from the external suppliers of energy and energy transit countries and try to integrate neighboring countries into the internal market.

Year 2030 [2] is currently the second goal when it comes to EU's strategy to reduce usage of fossil fuel and replacing it with renewable energy sources. There will no substantial cost difference compared to what would normally be needed since there is still a need to replace the ageing technology. Instead it will be a shift in focus on where to spend the money which will be away from fossil fuels and towards low-carbon technologies. The targets for year 2030 will be a 40% cut in greenhouse gas emissions compared to 1990, at least a 27% share of renewable energy consumption and at least 27% energy savings compared with the business-as-usual scenario. To help achieve these targets three policies have been put in place.

- A reformed EU emission trading scheme (ETS)
- Indicating security of the energy system and competiveness to achieve things as, diversification of supply, interconnection capacity between EU countries and price differences with major trading partners.
- Plan a new governance system based on national competitive, secure and sustainable energy to ensure stronger investor certainty, enhanced policy coherence, greater transparency and improved coordination across EU.

The last goal that currently exists is to reduce the amount of greenhouse gas emissions by 80-95%, when compared to 1990. This is to be done by the year 2050 [3] and to be able to achieve this the roadmap explores the transition of the energy system in such a way that it would be compatible with the reduction of greenhouse gas while also increasing the security of supply and competiveness.

There also needs to be significant investments made into new low-carbon technologies, grid infrastructure, energy efficiency and renewable energy. Since the investments cover a long period of time there needs to be policies in place that promote a stable business climate to encourage the investments to be made. EU set out four main routes, energy efficiency, nuclear energy, renewable energy and carbon capture and storage in 2011 to a more sustainable energy system in 2050. This is the conclusions of the analysis.

- It's economically and technically feasible to decarbonize the energy system. It's cheaper to achieve the emission reduction target then continuing with the current policies in the long run.
- It is crucial to increase the share of renewable energy and use the energy more efficiently regardless of energy mix.
- When replacing infrastructure use low-carbon alternatives to avoid costly changes in the future. Investments made in the power sector after 2020 will cost 4.3 times more according to the International Energy Agency.
- It is expected that the European approach will result in more secure energy supplies at a lower cost when compared to individual nationalities. Since the energy market will cover whole Europe the energy can be produced where it is cheapest and delivered where it's most needed.

Through the attainment of these targets, the EU can help to keep energy affordable for consumers and businesses while fighting the climate change and air pollution by decreasing its dependence on foreign fossil fuels.

2.2 Swedish policies

Sweden [4] has a very strong sense of moral when it comes to climate change. Because of that there is a very strict view on greenhouse gas emission. By 2020 Sweden hopes to have achieved at least 50% of renewable energy use where at least 10% of that is in the transport sector. The goal is also to achieve 20% more efficient energy use and a 40% reduction in greenhouse gas emissions. The vision is to have replaced all fossil fuels for heating by 2020 and by 2030 there will be a vehicle stock that is independent of fossil fuels. From the year of 2050 there will be a sustainable and resource-efficient energy system and no net emissions of greenhouse gases, but the ambition is to have a 100% renewable energy system in the longer term.
The policies Sweden uses to reach their target and that have gotten them this far is:

- Energy tax on electricity and fossil fuels
- Carbon dioxide taxation since 1991
- Green certificate system for RE since 2003
- Emission trading of CO_2 in EU

There is also a few recent policy initiatives:

- The ambition for the electricity certificate system to 2020 has been increased.
- Tax reduction for micro-generation of electricity.
- Increase the budget for solar power but reduce the percentage of investment support.
- Support a storage system for households to produce their own electricity.
- Develop a strategy for solar power.

There are also other instruments put in place to help achieve quicker change from fossil fuels to renewable energy. Some of the factors are education, the spread of information, innovation and RD&D (Research, Development and Demonstration). Because of that there have been various specific programs and support schemes put in place.

3 COMBUSTION TECHNOLOGIES

3.1 Biofuel

Caio Pereira, Gongliang Wang and M_ario Costa [5] did a study on the combustion of biodiesel in a large-scale laboratory furnace to assess its feasibility and for comparison purposes a petroleum based diesel was used. The results from the combustion reveal that the CO2 emission is very similar and not affected by atomization quality. A way to reduce the CO2 emission rapidly is to increase the excess air level of O2, up to a level of 2% of the flue gas. When it comes to the NOx emission the biodiesel combustion are always lower than that of the petroleum based diesel, but it will increase slightly when spray quality improves. The atomization quality will greatly influence the impact on PM emissions with the diesel having significantly higher PM emissions compared to biodiesel. The biodiesel PM emissions consists of elements such as Ca, Mg and Fe.
Wei-Checn Huang, Shuhn-Shyurng Hou and Ta-Hui Lin [6] **studied the combustion characteristics of a 300 kW_{th} oil-fired furnace using castor oil blended with diesel**. A mix ratio of 5%, 10%, 20% and 30% castor oil in the pure diesel was used. The comparative investigation was done by focusing on the wall temperatures in the radiative section of the furnace, gas temperatures in the convective section and emission product from combustion. Optimum operating conditions of excess O2 was used during all the experiments that were performed. The air supply requirement for pure diesel and 5%, 10%, 20% and 30% castor oil at a fixed liquid fuel supply of 20L/h were 245, 241, 240, 237, and 236 Nm^3/h, respectively. During the experiment the combustion was observed to very stable at all fuel blends. The wall and gas temperature remained very close compared to pure diesel, but dropped slightly with increased amount of castor oil. While the NOx emissions decreased slightly the CO2 emissions increased by a small amount it still remained relatively close to pure diesel. It is therefore verified that a blend of castor oil and diesel blend is a valid choice since it will produce similar results to pristine diesel.

3.2 Oxyfuel

There have been pilot trials at MEFOS that have proven that a new S3 Blast furnace gas burner can give high performance, low NOx and low cost reheating for the steel industry. The furnace was tested by using MEFOS chamber furnace were 40% of the energy came from propane (LPG) as the booster fuel, but natural gas can also be used. The booster fuel is recommended to use when faster steel reheating is wanted. During the trials an investigation of the environmental emission and reheating rate was done both with and without the booster fuel. There appeared to be no problem with unburnt CO and the NOx emissions were low. The multi-fuel burner will proved the industry with a system capable of providing a wide range of performance from high performance, high productivity furnace with propane-oxyfuel to lower cost operations with pure BFG-oxyfuel. Because of the reduction of fossil fuel consumption with LPG-oxyfuel the greenhouse gas emissions will be lower. Even greater reduction can be achieved by using process gases which would otherwise be flared.

4 HYDROGEN

4.1 Hydrogen production

N.A.Bulycheva, M.A.Kazaryana, A.S.Averyushkina and A.A.ChernovbA.L.Gusevc [8] did **a study on how to produce hydrogen by low-temperature plasma initiated in liquid media** was made where the inter-electrode discharge gap is able to decompose hydrogen containing organic molecules. This will result in a product in gas form where the hydrogen volume part is higher than 90%. From the calculations of energy efficiency that have been done in regard to hydrogen, feedstock healing value and energy consumption have shown an efficiency factor of 60-70%. The efficiency factor will be influenced by the source mixture composition. From the theoretical model calculation done the discharge current and voltage values are in good comparison to the experimental data.
Archita Sharma and Shailendra Kumar Arya [9] reviewed the **production of hydrogen can be done from algee biomass** with the help of photobioreactors and open-air systems. The photobioreactor allows for a careful cultivation control while the open-air system is a cheaper and simpler version. There have been encouraging optimization access included, called algal cell immobilization which have resulted in increased productivity per volume of a reactor and addition of the hydrogen production-phase.
A.M. El-Melih, A. Al Shoaibi and A.K. Gupta [10] studied the potential of hydrogen production from hydrogen sulfide and methane mixtures in nitrogen through an experimental investigation. Reformation of H2S in natural gas represents a viable alternative option for treatment of acid in gases extracted from gas wells that contains H2S, CH4 and N2. To investigate the effect of temperature and inlet stream composition on the product of hydrogen a laboratory-scale quartz reactor was used. The mixture used to produce the hydrogen consisted of hydrogen sulfide and methane diluted in nitrogen. The results revealed what a vital role reactor temperature on the decomposition of both hydrogen sulfide and methane does to the production of hydrogen. At temperatures exceeding 1473K the production of hydrogen increased dramatically in which the conversion of hydrogen sulfide is more significant. The methane was consumed at temperatures above 1373K, but the conversion of hydrogen sulfide was higher in the presence of methane than alone. Not only did the conversion increase with temperature but also the formation of carbon disulfide increased. The reactors operational conditions for the reformation of methane with hydrogen sulfide are favorable according to the results provided. They also provide a viable alternative option for the treatment of various waste streams containing hydrogen sulfide to produce clean hydrogen and sulfur.
Qingyu Wei, Yan Yang, Junyi Hou, Huan Liu, Fei Cao and Liang Zhao [11] **studied a new compound parabolic concentration (CPC) for direct solar photocatalytic hydrogen production has been designed**. The parameters of the CPC are designed according to the local meteorological conditions. The system includes 76 units with a total light area of 103.7m^2, where each unit is designed as a north-south orientated, adjustable, single axis tracking truncated CPC with the concentration ratio of 4.22. The units also have 4 different angles with inclination being 25°, 35°, 45° and 55°. The system is generally operated through natural circulation with the help of high pressure gas perturbing the sedimentary photocatalysts now and then. Early results show that the mean hydrogen productivity and cumulative hydrogen generation are 7.14 NL/h and 42.84 NL/day from the horizontal angle 25° row on a normal day. The average energy conversion efficiency is 0.087% and the daily generation of the whole system is accumulated to be 160.34 NL.

Maan Al-Zareer, Ibrahim Dincer and Marc A. Rosen [12], **studied the development of an integrated system based on coal gasification** to produce electrical power and hydrogen. All hydrogen produced is stored in a chemical storage media which consists of ammonia. The integrated system contains a water gas shift membrane reactor, a hybrid thermochemical water decomposition cycle based on the chemical couple copper and chlorine and a multistage ammonia production system. To meet the electrical requirements of the system a supporting combined cycle fueled by hydrogen is used. From the gasified coal syngas is water shifted in a membrane reactor to produce hydrogen. The syngas left is combusted to create energy for the system through a gas turbine. The water decomposition cycle and hydrogen output from the coal gasification are fed to the ammonia production system and the supporting combined cycle. To achieve a high conversion of hydrogen in the ammonia production system, it contains multiple stages. Feeding the ammonia system with nitrogen is a cryogenic air separation unit, which also provides oxygen to the gasifier. Looking at the results this system is capable of producing 0.18kg/s of hydrogen and 1.2MW of power per 1.5kg/s of coal. The system also has an energy efficiency of 48.7% and a exergy efficiency of 48.4.
Duman and Yanik [13] describes, in this study, the two-step steam pyrolysis of biomass for hydrogen production was evaluated based on different char catalysts. The different catalysts used were biomass char, nickel loaded biomass char, coal char and iron or nickel loaded coal chars. Methods used to characterize the catalysts were the Brunauer–Emmet–Teller (BET) method, X-ray diffraction (XRD) analyzer, X-ray fluorescence (XRF) and thermogravimetric analyzer (TGA). The catalysts that had catalytic activity on the hydrogen production were, Ni and Fe based coal char. The results showed that by increasing the temperature in the catalytic bed it enhanced the hydrogen production in presence of Ni biomass char, it also showed the highest catalytic activity based of hydrogen production. The biomass char was not thermally stable under steam pyrolysis conditions, but the steam has no influence on hydrogen production with a catalyst. On the other hand the coal char based catalysts remained unchanged after steam pyrolysis, which gives better thermal stability.

4.2 Hydrogen usage

Mehmet Salih Cellek and Ali Pınarbas [14] did an investigation on the performance and emissions while burning hydrogen-enriched natural gas and hydrogen in an industrial low swirl burner was made. To investigate the performance of burning the hydrogen, four different gas ratios was used at the same thermal load. The ratios consisted of 25%H2 +75%NG, 50%H2+50%NG, 75%H2+25%NG and 100%H2. To be able to study the turbulent flames, it was done numerically using ANSYS Fluent 16.0 for the solution of governing equations. The results revealed from burning hydrogen-enriched natural gas and pure hydrogen show a drastic decrease in CO and CO2 emissions, however the NOx emissions significantly increase due to thermal NO.

4.2.1 EU-countries hydrogen usage

The future importance of hydrogen used as an energy carrier will most likely grow. Therefore Pauline Caumon, Miguel Lopez-Botet Zuueta, Jérémy Louyrette, Sandrine Albou, Cyril Bourasseau and Christine Mansilla [15] in **France** are looking at the alternatives of implementing hydrogen production in its power system. Some of the possible applications are oil refining, decarbonize natural gas by injecting hydrogen into pipelines, or use hydrogen as a fuel. By combining CO2 with hydrogen it's possible to produce valuable product and at the same time reduce the CO2 emissions which is necessary if one means to decarbonize EU's energy system. From studying the flexibility the demand of electrolyzes would have on the power system while keeping hydrogen production close to competiveness, results show that only proactive scenario with high penetration rate of decarbonized energy will enable enough competitive production of low-carbon hydrogen. Creating a demand of electrolyzes mitigates almost all renewable energy. This shows that hydrogen production can help renewable energies to be integrated into the power system.

Mihajlo Firak and Ankica Đuki [16] in **Croatia** is looking at the possibilities of storing renewable energy in the form of hydrogen. This is going to be done by having hydrogen fuel cell electric vehicles on the roads. It was therefore proposed to have hydrogen infrastructure based on photovoltaic technology solar energy conversion and water electrolysis as adopted hydrogen production technology. The installed hydrogen infrastructure will be incorporated into the national grid power system as renewable energy production, energy consumption and energy storage subsystem.

4.3 Hydrogen EU-initiatives

The INGRID project [17], funded within the 7th framework Energy program for RTD, was started to demonstrate the effective usage of safe, high density, solid-state, hydrogen storage systems for power supply and demand. To match the energy supply and demand the INGRID project will combine the most recent advances on hydrogen-based energy storage in Smart Grids. While ensuring stability and security to the power distribution network, it will optimize the electricity generated by intermittent Renewable Energy Sources. The objectives of the INGRID project are:

- Integrate larger yet decentralized, fluctuating renewable energy sources effectively without compromising the grid security and reliability.
- Make and design available advanced ICT monitoring and control tools aimed at managing, simulating, monitoring and controlling power dispatching. This should be done in compliance with the power grid to allow a correct balance between energy supply and demand.
- Demonstrate the innovative hydrogen solid-state storage as a safe and high density storage system. The system is to be integrated into a closed loop connected to a water electrolyzers and fuel cell system to achieve a high efficiency regenerative loop (50-60%).
- Perform demonstrative small scale tests for the assessment of the storage systems balancing capabilities in presence of high variable electricity demand.

Hopefully the INGRID project will increase the value chain of green hydrogen and propose a win-win business model for electric storage. The role of hydrogen based technologies in supporting renewable energy integration and power supply and demand balancing will be unveiled.

The Council of the European Union decided on the 6th of May 2014 to continue the **Fuel Cells and Hydrogen Joint Technology Initiative under the EU Horizon 2020 Framework** [18]. It will cover the industry, research and European Commission on a matched basis with a total budget of €1.33 billion. The objectives of the initiative are:

- Increase lifetime of fuel cells to compete with conventional technologies while reducing production costs.
- Reducing operational and capital costs of hydrogen production, mainly from water electrolysis while increasing energy efficiency to make the system competitive with available alternatives.
- Demonstrate the feasibility of using hydrogen to support integration renewable energy sources into the energy systems on a large scale.
- Reduce use of “Critical raw material” by avoiding, reducing or recycling rare earth elements and have low or platinum free resources.

The FCH will last until the 31 of December 2024 and will bring private and public interest together in a new, industry-led implementation structure, to ensure that the jointly defined research program better match the industry’s needs and expectations.

5 RECENT RESEARCH PROJECTS AND EQUIPMENT

5.1 Electric Heating: Induction Heating

Swerea MEFOS has a 900 kW ASEA Induction heater for billets and blooms
Many studies have been made in over 30 years of research for example rapid inductive heating of stock after a conventional furnace was investigated in the TO32 project ”Energieffektivare driftsstrategi för valsning av avancerade stålprofiler”. (JK32074--2011)[1] and blooms reheating in BTF 86013 ”Induktionsvärmningsförsök med 125x300x1800 mm St37 kolstål i BTFs induktionsvärmare” (B. Leden, A. Rensgard-1986)

Plus Swerea MEFOS has invested in a new 200 kW Teknoheat high frequency inductive strip heater in the EU NorFast project (ends 2018)

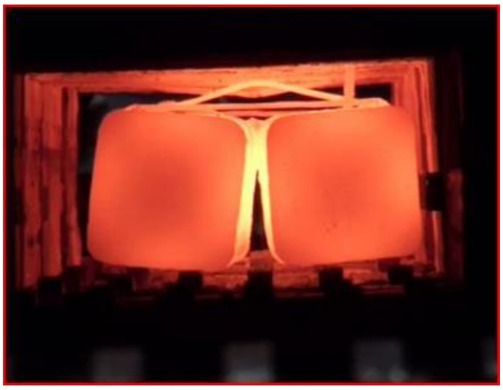
Some Factors Influencing Induction Heating

- Coil design and stock geometry
- Induction current and frequency
- Material properties and ferromagnetism
- Temperature range
- Stock velocity

Some Advantages of Induction Heating

- Rapid reheating (high productivity with low oxide scale losses)
- Environmentally friendly (no exhaust gases or CO2)
- Local or spot heating is possible (strip edges)
- High process efficiencies are possible

[1] TO32-JK32074: Jan-Olov Perä, John Niska, ”PILOTFÖRSÖK MED INDUKTIV PÅVÄRMNING AV KULLAGERSTÅL FRÅN OVAKO INOM PROJEKTET "TO32 ENERGIEFFEKTIVARE DRIFTSSTRATEGI FÖR VALSNING AV AVANCERADE STÅLPROFILER”, MEF10008, 2010 och J-O Perä Slutrapport, MEF 11012, 2011..

Figur 1Visual evidence of higher temperatures near the billet surface due to the magnetic field penetration depth profiles

5.2 Resistive Heating

Options
Indirect resistive heating with Kanthal elements or similar equipment in the furnace or for preheating air

- MEFOS Bell furnace
- NyCast Gas heating
- Dual heating/Skidmark removal with electric heating

Advantages:

- Can be used for preheating the furnace combustion air to 1000°C and fuels (some fuel temperatures as BFG are limited by fuel decomposition)
- Technology installed and proven for the MEFOS fluidbed reactor**
- Compact units with high gas velocities
- High gas temperatures and pressures are possible with insulated outer walls
- Over 95% efficiency for the NyCast gas heater when powered with electricity—but additional power losses will come for the power transmission and control systems.
- Separation of the gas and the heating elements protects the elements from contamination for a longer life.

Direct resistive heating with the electric current through the stock

- MEFOS ASEA resistive heater for strip
- Billet reheating (Ramnäs Bruk)

Indirect Resistive Heating: Conventional Bell Furnace at MEFOS

Examples of Projects

- Stock preheating for boosting productivity or advanced reheating curves together with the combustion furnace fired chamber furnace (RFCS HELNOx project)
- Inert gas annealing/heat treatment
- Indirect Booster Resistive Heating in MEFOS WBF (EUR19855)

5.3 Oxyfuel Combustion of Blast Furnace Gas (BFG) – A Low Calorific Value Fuel or Any Fuel Mixture

Advantages:

- Use of process gases or hydrogen mixtures reduce CO2 emissions – Governmental / Regulatory goal
- BFG saves on the purchase cost of energy/fuels – More cost competitive
- Strategic planning – Independence from imported fuels
  - Middle East oil uncertainties with OPEC pricing
  - Russian oil and gas supplies with political pressures
  - Produce domestic biofuel gases or hydrogen
- Oxyfuel technology can increase the furnace productivity

Disadvantages:
- High capital costs to install a new fuel supply and control system, gas preheating and/or oxyfuel combustion in industrial furnaces
- The blast furnace process could be replaced by CO2-free steelmaking

RFCS Project: HELNOx- BFG. "High efficiency low NOx BFG based combustion systems in steel reheating furnaces" , RFSR-CT-2012-00010, July 2012 - Dec 2015

6 CONCLUSION

- Important to find alternative and flexible heating solutions are important
- The industry will need new energy efficient solutions and ways to decrease CO_2 emisisons
- Fuel flexibility; H_2, H_2 – Electric, Biogas, are ppossible alternatives
- Fuel flexibility as a concept has ot been studied, few projects are ongoing. RFCS (0), EU H2020, FP5-7 only few projects not necessary focusing on fuel flexibility.
- The overall economics for the selection and use of hydrogen or electricity to replace the use of fossil fuels needs to be evaluated (process integration activities)
- The lack of historical data for calculating accurate capital and operating costs for new equipment and technology can make comparisons difficult, for example:
  - Costs for hydrogen gas transportation and storage if a combustion process based on renewable energy is chosen (versus a more stable energy source as 4th generation liquid lead nuclear power)
  - Future peak electrical rates if industry and society choose a high percentage of wind and solar energy
  - Maintenance costs and requirements for new equipment
  - The requirements for stable operation (what backup fuel would be available if there is an electrical blackout or hydrogen fuel shortage?)
- Pilot trials and industrial furnace conversion to partial electrical heating or partial hydrogen combustion could be the most secure way to test new technology.

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Swerea MEFOS
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Swerea MEFOS, Box 812, 971 25 Luleå, Sweden
Phone. +46 (0)920-20 19 00 • www.swereamefos.se

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FORSKNING

TO 51-66

Literature survey on fuel flexibility of heating furnaces in the steel industry

Joe Liang
Student at Uppsala University

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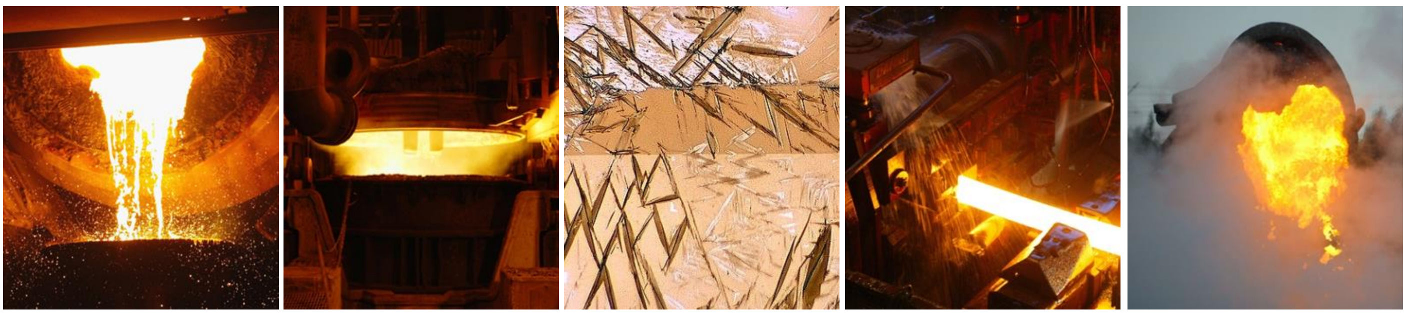

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SSAB Europe Oy
SSAB Special Steels
Uddeholms AB

Summary

This report is the result of four weeks of summer job financed by TO51 and examines available information on fuel flexibility of reheating furnaces in the steel industry, to serve as input for the upcoming project: FlexVärmeStål, which starts in September 2017. Currently used fuels in reheating furnaces are limited, however, technology such as oxyfuel allows for greater flexibility by using both liquid and gaseous fuel. Alternative fuels and ways of using fuel have been explored both in research institutions as well as in other industries, either through gasification or additional burners respectively. There is also an increasing interest in using hydrogen as a fuel in various industries, the steel industry included, in order to minimize CO_2 emissions. The number of projects involved with hydrogen as fuel for reheating furnaces are limited, but the potential of projects involved with industrializing hydrogen should be considered in the future as well.

Sammanfattning

Den här rapporten är resultatet av fyra veckors sommararbete finansierat av TO51 och är en granskning tillgänglig information på bränsleflexibilitet i stålvärmningsugnar, som grund till ett kommande projekt: FlexVärmeStål, som har start September 2017. De tillgängliga bränslena i stålvärmningsugnar är begränsade, dock kan teknik såsom oxyfuel tillåta en större flexibilitet genom att använda flytande bränslen eller bränslen i gasform. Alternativa bränslen och metoder för att använda bränsle har utforskats på både forskningsintitut såväl som andra industrier, antingen genom förgasning respektive ytterligare brännare. Det finns även ett ökat intresse för använding av väte som bränsle i andra industrier, inklusive stålindustrin, för att minimera koldioxidutsläpp. Antalet projekt som är involverade i att använda väte som bränsle för stålvärmningsugnar är begränsade, men det finns potential i projekt som är involverade i att industrialisera väte och dessa bör beaktas i framtiden.

Key words:

Heating furnace, steel industry, fuel flexibility, GHG mitigation, renewable fuels, burner technology

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1 INTRODUCTION

There is generally a global consensus to work towards a more sustainable future, through innovative technology and to widen the usage of renewable resources. This has caused communities, companies and nations to join forces with ambitions to fulfill goals which meet certain criteria. Initiatives are from organizations which range from the World Business Council for Sustainable Development (WBCSD) to the European Union, both of which connect people internationally, to national regulations and laws which work within more restricted boundaries. WBCSD have outlined their goals through their agenda, Vision2050 which also includes their medium-term agenda of Action2020. These two agendas aim to obtain sustainable development through clever business solutions and scientific achievements for 2050 and 2020 respectively.[1] The European Union drives development via legislation well as within Horizon2020, which aims to keep Europe at the forefront of socioeconomic development through research and innovation.[2] Sweden is subject to national and EU regulations to increase the amount of carbon dioxide neutral and renewable fuels according to the goals and ambitions set to 2020 and 2050 respectively. This is especially relevant to the steel industry as it is the largest emitter of carbon dioxide in Sweden. [3]

The aim of this report is to examine available information from internet sources and the scientific literature which can serve as background information for future research on fuel flexibility of heating furnaces in the steel industry. It is designed to serve as an input to the project: Flexible solutions to decrease greenhouse gas emissions from heating furnaces in the steel industry (FlexVärmeStål) which will start in September 2017, funded by the Swedish Energy Agency. The focus is on the possibility for flexible use of different types of fuel (biofuel, hydrogen, LNG, propane, oxygen) with a special emphasis on hydrogen in order to complement a previous survey on biofuels.[4] In addition to examining the steel industry, reported experience from heating furnaces in other industries, and from the power generation sector, are considered. The report is divided into two parts: what is currently being utilized in the industry, which is separated into currently used fuels and methods and the difficulties which are faced in the industry; and what could soon be commercialized or is in the research and development phase, based on a literature survey.

2 METHODS

The literature survey was conducted through review of articles, reports and, conference papers on currently known knowledge as well as to be published articles within research. Weekly discussion sessions were held with supervisor Rachel Pettersson and affiliates to the project FlexVärmeStål for feedback and sharing of knowledge. A visit was also made to SSAB in Borlänge, to see heating furnaces and other equipment in the steel industry first hand as well as discussing with Jonas Engdahl and Matts Persson.

3 RESULTS

3.1 Currently used fuels and methods

There are a variety of fuels used today in heating furnaces. For instance: SSAB in Sweden, uses Liquefied Natural Gas(LNG) and Liquefied Petroleum Gas(LPG) in their heating furnaces,[5] while coke, coke oven gas(COG), blast furnace gas(BFG) and coal are commonly used in the US.[6] It is common for a reheat furnace to use low calorific content gases such as the aforementioned COG, BFG or Blast Oxygen Furnace Gas(BOF gas) or any mixture of them.[7][8] However, a common aspect of the aforementioned fuels is that they are neither carbon dioxide neutral nor renewable. Renewable in this context is used to mean that the net effect of CO2 emission from it is zero.

The commonly utilized fuels can be used in conjunction with oxyfuel technology which is based on using pure oxygen instead of air during combustion, which improves overall thermal efficiency and decreases the amount of fuel used. [10] Oxyfuel based solutions have been provided by AGA since 1990 to reheating and annealing furnaces in various industries, the steel industry included. [9] AGA has since 2000 been a part of the Linde Group. A further development is the flameless technique which in this context means that the combustion flame is not seen or easily detected with the naked eye. This has, for example, been installed at Outokumpu in Nyby and SSAB in Borlänge. In these oxyfuel solutions, the fuel used in the reheating furnaces has been oil. [10] However, oxyfuel processes are also capable of utilizing gaseous fuels as well, which include LPG, natural gas, acetylene and hydrogen.[11]
Linde group is currently the leading provider of oxyfuel based solutions globally, with reference installations of flameless oxyfuel for the steel industry located in Europe, the Americas and in Asia. [10] This is where the commercial level of the steel industry is globally.

3.2 Industrial situation and its difficulties

Because of the lack of renewable fuels, current research has explored new possibilities for fuel usage and alternative fuels in reheating furnaces. This is seen in the study[12] conducted by Harlin and Sandell in 2013 at the Division for Energy and Furnace Technology at KTH in Stockholm, where it was experimentally verified that syngas would be best suited with regards to mitigating CO2 emission, especially when produced using biomass. Syngas, or synthesis gas has its name derived from being an intermediate product which is used to synthesize other chemicals, but can also be used as fuel.[12] The general idea of implementing syngas production and usage into industrial application was also addressed. However, as discussed by Duclos in 2014[13], the difficulty of producing quality syngas is seasonally dependent and it is not as cost competitive as other fuels as transportation costs needs to be factored in. The latter can be solved through on-site gasification coupling to the furnace of choice or transformation into SNG and then further transported through existing gas grids.

Apart from current research within the steel industry, other industries can also bring forth ideas such as Alstom in Switzerland whereby using so-called EV and SEV burners are able to combust mixture of fuels in different proportions. This allows their gas turbines to run on different fuels depending on the circumstances, such as availability or emission control.[14] Similar fuel flexibility is also obtained by Siemens,[15] in their gas turbines. Siemens also addresses the possibility of using hydrogen as a fuel and they are currently capable of adding up to 45 percent of hydrogen into the fuel mix. However, the problem with corrosion and flame speed is apparent and it poses certain requirements on the burners to control the flame speed and to withstand long term corrosion.

3.3 Ongoing projects and potential fuels

There are also ongoing projects which focus on renewable fuels for other applications in the steel industry. Ultra-Low CO2 Steelmaking(ULCOS), which is a consortium within the EU, launched in 2004, a cooperative research and development initiative to enable drastic reduction of CO2 emissions from steel production. In the consortium, there are specific targets such as the commercialization of biomass in the three different phases(Solid, liquid and gas) through research and development.[16] Specifically, the conversion of renewable resources into solids is currently of interest at Kessel University, Germany,[16] Moreover, ULCOS consists of expertise in conversion of biomass to its corresponding liquid and gaseous forms at Biomass Technology Group(BTG), The Netherlands and at CRM, Belgium respectively.

Out of the many projects, there are a few which are focused on the steel industry and even fewer are focused on providing hydrogen for the heating/annealing process of steel making.

H2FUTURE is one such project, which specifically targets steel making through iron ore reduction at voestalpine. The project aims to produce hydrogen on a large scale to supply hydrogen markets through demonstration of a large-scale electrolyzer. H2FUTURE intend to finish their project by 2021, having a demonstration ready plant by then.[17]

Hydrogen Breakthrough Iron-making Technology (HYBRIT) is joint project between SSAB, LKAB, Vattenfall, which also focuses on steel making. They take a different approach to reduce carbon dioxide emissions from iron making. By using hydrogen, produced from “clean” electricity, for iron ore reduction, the by-products would then be water instead of carbon dioxide, which makes for a more sustainable steel making process. The plan is to have their demonstration plant trials by 2025 and evaluation for 10 years thereafter.[18]

Then there is Green Industrial Hydrogen(GrInHy), which is a project based off Solid Oxide Cell(SOC) technology to produce hydrogen by electrolysis. An on-going project, with goals to implement the technology into existing infrastructure in industries, with the steel company Salzgitter Flachstahl as the relevant industrial connection. Unlike H2FUTURE and HYBRIT, GrInHy sees the possibility of using hydrogen as fuel for heating furnaces or as inert gas from annealing purposes. The timeline is shorter than for the previously mentioned projects, in that GrInHy set their target year as 2019.[19]

Finally, there is Linde which, along with providing effective solutions for mitigating the effects of climate change, is also at the forefront for the hydrogen market. With broad experience and specializing in gas, Linde has become one of the largest providers of hydrogen through production, distribution and fueling. Linde partake in several initiatives and multi-partner projects in order to provide the automotive industry with hydrogen for storage and fueling, such as HyWays, StorHy and H2Mobility just to name a few.[20]
They also provide the integration and construction of on-site facilities of hydrogen production.[21]

4 DISCUSSION

Currently used fuel in reheating furnaces are neither carbon dioxide neutral nor renewable and therefore produce a net contribution to global CO2 emissions. Oxyfuel solutions combat this problem by using oxygen instead of air during combustion, to reduce CO2 emissions but since the fuel is not carbon free, the net carbon dioxide emissions will not be reduced to zero. The fuel flexibility in reheating furnaces is more apparent in specialized companies such as Linde and even then it is limited to liquid or gaseous fuel and not any mixtures of fuels.
Instead of mixing fuels, other alternatives of fuels such as biomass based fuels which are renewable fuels, can be considered. Biomass fuels are still a work in progress but it has been experimentally verified that syngas is best suited for reducing CO2 emissions.

The burner seems to be the most vital piece of equipment when it comes to being able to achieve fuel flexibility and mixing of fuels, as seen from the power generation industry. The trade off is that for different proportions of fuel used, the corrosion on the burner and combustion flame behavior will differ. This poses strict requirements on the burner used.

5 CONCLUSIONS

The presented scope of information is less than what might be available due to limited distribution by original publisher of some of the literature. Other sources refrained from publishing complete information, leading to inconclusive results for the literature survey.

Future possibilities to relevant information may arise from the research done on reheating furnaces at the Division of Energy and Furnace Technology at KTH in Stockholm. This includes research done on alternative fuels, equipment used in conjunction with reheating furnaces and thermodynamical studies inside reheating furnaces.

Furthermore, there are also a number of joint projects, initiatives and consortia addressing goals focusing on climate change. Many of these joint projects also have a common vision of industrializing hydrogen, and the Swedish steel industry is no exception. Although all of the hydrogen specialized R&D are in their premature stages, the interest for hydrogen is continuously expanding which can be seen with the widespread of distribution made by Linde. This can be regarded as a promising basis for the possibility of using hydrogen as fuel in the steel industry in the future.

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STÅL FORMAR EN BÄTTRE FRAMTID

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Box 1721, 111 87 Stockholm · Kungsträdgårdsgatan 10
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JERNKONTORETS FORSKNING

TO 51-65

Litteraturstudie: elvärmning som komplement / ersättning till förbränningsugnar för stålvärmning

Literature survey: Electric heating as a supplement / alternative to combustion heating of steel heating furnaces

David Söderberg,
Student inom Hållbar Energiteknik vid Luleå Tekniska Universitet

Kommitté TO51 publicerad 2017-08-14
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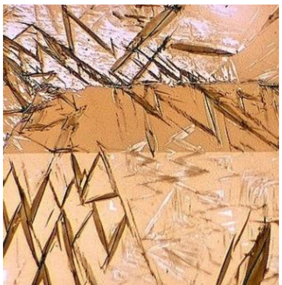

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Denna rapport är öppen endast för personer inom följande företag som deltar i verksamheten inom TO51 och/eller projektet FlexVärmeStål.

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Sammanfattning

Den här rapporten är resultatet av fyra veckors sommararbete finansierat av TO51. Den är en sammanställning av nuläget vad gäller elvärmning som komplement, dellösning eller ersättning till förbränning i värmningsugnar, med fokus på samspel mellan elbaserade lösningar och traditionella förbränningslösningar. Sammanställningen grundar sig i en litteraturstudie av vetenskapliga artiklar och en undersökning av företagsinformation. Resultatet visar att vetenskapliga undersökningar om samspelet mellan elbaserade och traditionella lösningar knappt existerar. De artiklar som hittades inom området kommer från industri och visar fördelar som lägre förbränningstemperatur, mindre bränsleförbrukning, och mindre skalbildning. Det finns ett påtagligt behov av forskning inom området.

Summary

This report is the result of four weeks of summer job financed by TO51. It is a summary of the current situation of electric heating as a complement, part solution or replacement of combustion furnaces, with focus on the interaction between electrical- and combustion solutions. The summary is based on a literature study of scientific articles and research of corporate information. The result shows that scientific research of the interactions between electrical and traditional solutions barely exists. The articles that has been found in this area comes from corporate research and they present advantages such as lower furnace temperature, less fuel consumption and reduced scale formation. There is a significant need for more research in this area.

Nyckelord: elvämning, elbaserade värmningslösningar, induktionsvärmning, resistansvärmning, plasmavärmning, kombinerade värmningslösningar, dellösning, integrerad induktionsvärmning, kompletterande elvärmning

Key words: electric heating solutions, induction heating, resistance heating, plasma heating, combined heating solutions, part solution, integrated induction heating, electric heating, complementary electric heating

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INNEHÅLLSFÖRTECKNING

1 INLEDNING

Stålindustrin arbetar mycket aktivt med utveckling av värmebehandlingsprocesser och värmningsugnar. Möjligheten att använda en ökande mängd förnybar energi eller bränsleformer med lägre CO_2 utsläpp är ett högprioriterat område. Hösten 2017 kommer förstudien FlexVärmeStål starta. Förstudien går ut på att bidra till stålindustrins utfasning av fossila bränslen i stålomvärmningsugnar för att vara CO_2 neutrala till 2045. Den här rapporten är tänkt att ge bakgrundsinformation till förstudien angående rapporterat användning av elvärmning som komplement, dellösning eller ersättning till förbränning i värmningsugnar med fokus på samspel mellan elbaserade lösningar och traditionella förbränningslösningar.

2 METOD

Slutsatserna i denna rapport grundar sig på litteraturstudie av vetenskapliga artiklar hämtade genom LTUs tillgängliga databaser, kontakt med industri, samtal med handledaren samt övergripande sökningar på internet. Lista över de vetenskapliga databaser som sökts i kan ses i Bilaga 1. Då LTUs sökmotor för vetenskapliga artiklar inte innefattar publikationsdatabasen DiVA, har individuella sökningar även gjorts i den databasen. De industrier som kontaktats är:

- SMS-Elotherm
- Inductotherm
- EFD Induction
- ABP Induction
- Kanthal Heating solutions

Ett studiebesök vid SSABs valsverk i Borlänge har också gjorts. Undersökningen utfördes under 4 veckor sommaren 2017. På grund av semesterperioden har det varit svårt att komma i kontakt med rätt personer inom industrin. Samtliga av de företag som har kontaktats har hänvisat till efter semesterperioden.

3 RESULTAT

3.1 Induktion

Uppvärmning genom induktion erbjuder snabb, kontaktlös och högeffektiv uppvärmning av materialet. Induktionsvärmning bygger på att man kan skapa magnetfält med hjälp av växelström. Utsätts ledande material för detta magnetfält skapas värme genom två olika fenomen; virvelströmmar och hysteres. Virvelströmmar är orsaken till majoriteten av värmeutvecklingen inom induktionslösningar, i ferromagnetiska material skapar även hysteres värmeutveckling. Då virvelströmmar huvudsakligen uppkommer vid ytan av materialet är det vid ytan som den största värmeutvecklingen sker (Oscar Lucia, 2013). Detta fenomen är även känd som "skinneffekten". Hur djupt man kan värma stålet med induktionsvärmning beror på kolhalten, induktionsfrekvensen, induktionseffekten, hur lång tid den utsätts för induktion samt kylmedium. Ju lägre frekvens man använder desto djupare kan man nå. Då värmeutveckling delvis sker på grund av magnetisk hysteres påverkas verkningsgraden av induktionsvärmning negativt ifall uppvärmning ska ske till över curietemperaturen. Curietemperaturen är den temperatur som ett material tappar sina ferromagnetiska egenskaper och övergår till paramagnetiskt (Pye, 2010).
Beroende på storleken kan uppvärmningstiden på komponenter vara så låg som under sekunden, men t ex större slabs tar upp emot en minut att få homogent uppvärmd (Inductotherm, 2017). Vid induktion skapas värmen direkt i materialet istället för indirekt genom förbränning i ugnskammaren. Man kan då uppnå verkningsgrader på upp till 92-95% inom industriella induktionslösningar (Elotherm, 2017). Värmeutvecklingen är direkt kopplad till den ström som appliceras samt utformningen av spolen som används för att skapa magnetfältet, vilket skapar förutsättningar för hög kvalitet och repeterbarhet. Eftersom värmen skapas direkt i materialet kan förbränningslösningar undvikas, vilket minskar utsläppet av växthusgaser om den levererade elen kommer från koldioxidneutrala källor. Eliminering av förbränning kan även förbättra arbetsvillkor för de som arbetar i nära kontakt med förbrännare (Oscar Lucia, 2013).

För- och nackdelar med induktion är (Pye, 2010) (Inductotherm, 2017):

- Snabb uppvärmning.
- Hög verkningsgrad.
- Hög kontroll.
- Bättre arbetsmiljö.
- Lokal uppvärmning kan ske.
- Minimal ytavkolning.
- Minimal ytoxidering.
- Högre utmattningshållfasthet.
- Låga driftkostnader.
- Minskad ytkostnad, induktionsugnar kan vara upp till 10 gånger mer yteffektiva än förbränningsugnar.
- Minskat slitage vid valsning.
- Korta start- och stopptider.
- Höga investeringskostnader.
- Bara vissa stål är lämpliga att induktionsvärma.

3.2 Resistansvärmning

Resistansvärmning består av två olika typer av lösningar. Typ ett innebär att resistorer värms upp med hjälp av ström enligt Joules lag. Värmen överförs sedan till metallen i fråga med hjälp av konvektion och strålning, denna typ av resistansvärmning är kallad indirekt resistansvärmning. Typ två innebär att strömmen appliceras direkt på den metall som ska värmas, lösningen kallas direkt resistansvärmning. Direkt resistansvärmning är den ovanligare av de två då lösningen ställer krav på geometrin på den metall som ska värmas. Långa rör med liten diameter är den optimala geometrin, då det leder till snabb och homogen uppvärmning, lösningen kan då uppnå hög produktionshastighet och verkningsgrad (Lupi, 2017). Resistansugnar går att klassificera på tre olika sätt baserat på temperatur.

- Lågtemperatursugn, upp till 600 °C. Naturlig och påtvingad konvektion står för majoriteten av uppvärmningen.
- Medeltemperatursugn, 600-1300 °C. Strålning står för majoriteten av uppvärmningen.
- Högtemperatursugn, 1300+ °C. Även här står strålning för majoriteten. Vid dessa temperaturer är det vanligt med vakuumlösningar.

Vid högre temperaturer (1300+) är det inte längre möjligt med metalliska resistorer. Man använder då istället bland annat SiC, $MoSi_2$ eller grafit beroende på vilka temperaturnivåer som eftersträvas. Fördelar med resistansvärmning är (Takei, 2013):

- Hög verkningsgrad, ~90% för direktresistans, ~70% för indirekt (Kanthal, 2017).
- Minskad ytkostnad.
- Låga underhållskostnader.
- Inga gaser från förbränning - arbetsmiljö.
- Mindre oljud för arbetare – arbetsmiljö
- Mer anpassningsbar jämfört med induktion.
- Mindre utsläpp av växthusgaser.

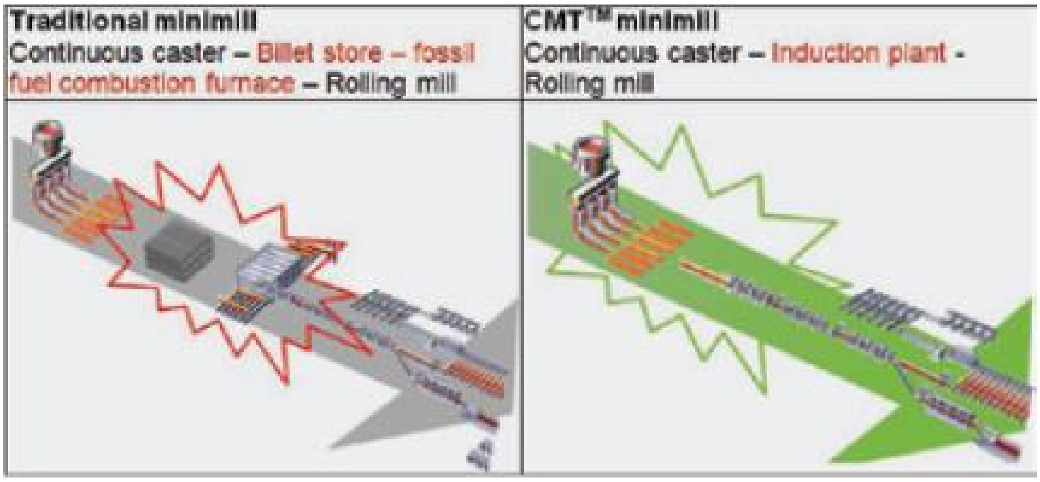
3.3 Plasmavärmning

Förenklat kan man säga att plasma är en gas som kan leda elektricitet. Plasma brukar kallas det fjärde aggregationstillståndet, och är vad som händer om man fortsätter pumpa energi in i ett ämne efter att det har förångats. När det når detta tillstånd blir det strömförande och kan utnyttjas för att värma material. Verkningsgraden på värmeöverföringen kan vara så hög som 95%, men då man vid tillämpning även måste skapa vakuum brukar helhetslösningen ha en verkningsgrad på 75-90% (Plasmait, 2017). Plasmavärmning lämpar sig bra vid höga temperaturer där traditionella förbränningsugnar inte fungerar effektivt. T ex vid 1600 °C kan bara 20% av energin i förbränningsugnar användas för att smälta metallen, medans 80% av energin i plasmavärmd luft är tillgänglig (HDR Power systems, 2017). Övergripande fördelar med plasmavärmning är:

- Hög stabilitet och kontroll av processen
- Låga produktionskostnader
- Låga start- och stopptider
- Fin och homogen kornstorlek

3.4 Ersättningslösningar

Ett exempel på en ersättningslösning är Tung Ho Steel i Taiwan som var beroende av olja och gas för deras smält- och valsverk. Deras driftkostnader var därför relativt höga. I ett försök att minska driftkostnaderna investerade de i en induktionslösning som ersätter uppvärmningen mellan stränggjutning och valsverket enligt figur 1.



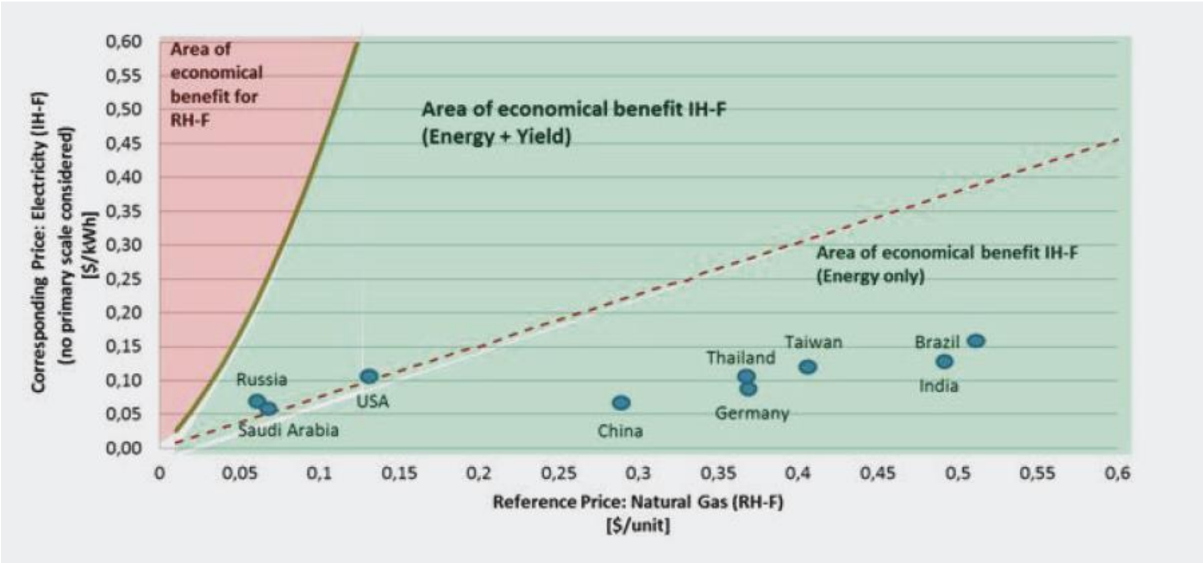
Figur 1- Före & efter, Tung Ho Steel

SMS Elotherm menar på att den traditionella lösningen, till vänster i figur , har en rad nackdelar.

1. Man låter stålet svalna för att sedan värma upp det igen, vilket kostar tid och pengar.
2. Skalbildning vid förbränningsugnar leder till förlust av produkt.
3. Skalbildning påverkar livslängden av valsverket negativt.

I de traditionella lösningarna så låter man ~30% av stålet svalna medans ~70% matas direkt in i förbränningsugnen för återupphettning. Med en 30/70 lösning där de varma billetsen har ca 1000 °C krävs det ca 155-160 kWh/t för att värma till lämplig temperatur. En induktionslösning, till höger i figur 1, som ständigt matas med 1000 °C billets och med hjälp av induktion värmer dem till lämplig valstemperatur endast kräver 20-25 kWh/t. Induktionslösningen gjorde även att skalbildningen minskade från 0,6% till 0,02%. Minskad energikostnad samt ökad mängd produkt var andra tydliga fördelar.

Beroende på var i världen man befinner sig så varierar kostnadsfördelen för induktionsvärmning. I figur 2 ser man ifall lösningen skulle ge vinst.



Figur 2 - Internationell jämförelse av kostnad, naturgasförbränning vs induktionsvärmning. Majoriteten av länder har förhållanden som gynnar induktionsinvesteringar enbart på bärnslekostnad. Länder som Ryssland skulle gå med vinst på grund av minskad skalbildning vilket leder till ökad mängd produkt. Sverige har snarlika förhållanden som Tyskland.

Tung Ho Steel bytte från en lösning baserad på råolja och lyckades med denna lösning spara 20 €/ton stål samt minska utsläpp av CO_2 med 72 000 ton per år, SO_2 med 410 ton per år samt NO_x med 225 ton per år. Tung Ho Steel består av en 120 ton EAF, med årlig produktionskapacitet på 1,2 miljoner ton billets. Valsverket producerar ca 800 000 ton per år. (Klaus von Eynatten, 2014)

3.5 Kompletterande lösningar

Kompletterande eller dellösningar syftar på lösningar som bygger på både elektriska lösningar samt traditionella förbränningslösningar. I de vetenskapliga databaserna hittades inga artiklar med fokus på detta område. Företagsinformation om sådana lösningar var också sällsynt. Övergripande ser det ut som leverantörer av värmningslösningar är mer måna om att förespråka helhetslösningar med deras produkt ,samt stå för underhåll och service, än dellösningar som de inte kan ge garanti på. Abdurahman et al 2012 visar dock att man med hjälp av förvärmning med hjälp av induktion kan minska storleken på bandugnar som används för att behålla temperaturen i slabsen. Det kan betyda en minskning av energibehovet med upp till 10%. Det är även en storlekseffektiv lösning för att värma upp stålet igen mellan valspar i längre processer. Induktionslösningar placerade efter förbränningsugnar gör är att förbränningsugnen kan köras på lägre temperaturer. Vilket medför lägre CO_2 utsläpp samt längre livstid för bland annat ugnens isolermaterialet. (Anis Abdurahman, 2012). Artuso et al. kom fram till samma resultat. Induktionsvärmning i senare steg leder till minskad temperatur i förbränningsugnen vilket förutom minskad skalbildning också minskade deras naturgasförbrukning från 55 m3/t till 49 m3/t, elförbrukningen ökade dock med 44 kWh/t (Artuso I, n.d.).

SSAB har investerat i olika typer av kombinationslösningar. Valsverket i Borlänge innehåller en kontinuerlig glödgningslinje med 2 induktionsugnar och därefter 4 gasolvärmda zoner.

4 DISKUSSION & SLUTSATSER

Denna litteraturstudie har försökt sammanställa information om elbaserade värmningsugnar, med fokus på samspel mellan el- och förbränningsugnar. Information om just denna typ av lösningar har varit väldigt svår att komma över. De vetenskapliga artiklar som dykt upp vid sökningar har syftat på allt från nya rön inom modellering vid kompletta induktionslösningar till hur kornstorlek påverkas av svetsning. Av de exempel av samspel som hittades kan fördelarna sammanfattas med:

1. Möjlighet till minskad temperatur i förbränningsugnen om efterföljande induktionsvärmning används. Detta ger fördelar som ökad livstid för isolermaterialet i förbränningsugnarna, mindre bränsleförbrukning samt mindre skalbildning.
2. Möjlighet till att värma upp och homogenisera värmen i stålet efter att det ytan har hunnit svalna. Till exempel mellan valspar.

Minskning av bränsleförbrukning bland denna typ av lösning kommer dock som följd av ökad elförbrukning. Det blir dock ett steg mot en koldioxidfri stålindustri då Sverige har goda förutsättningar för fossilfri elproduktion. Men kompletta elbaserade lösningar skulle i såna fall minska CO_2 utsläppen mer än kompletterande lösningar. Vad det skulle ha för effekt på elnätet, samt hur det skulle påverka stålkvalitéer kan jag bara spekulera. Men med den allt större utvecklingen av hållbar elproduktion, inte minst inom solenergin som nu levererar lägre elpriser än fossilbaserad el på flera håll, finns det fördelar i att ställa om till elbaserad stålvärmning. Då induktionslösningar är relativt små till storlek och har extremt korta start- och stopptider jämfört med förbränningsugnar har man stora möjligheter att anpassa sin produktion efter elprisets fluktueringar.

Vissa av de fördelar med induktionsbaserade lösningar försvinner när de kombineras med förbränningsugnar, t ex yteffektivitet, förbättrad arbetsmiljö, minskad skalbildning på faktor 30 som i fallet i Tung Ho Steel. Det kan bidra till att kombinerade lösningar inte finns i så stor utsträckning. Vad gäller plasmavärmning har det en relativt smalt användningsområde vid specialstål, och lämpar sig inte från ett ekonomiskt perspektiv vid vanligare stålprocesser. De ellösningar som enklast kan installeras i nuvarande processer är de som innehåller strålningsrör. Strålningsrören kan då konverteras till elbaserade rör istället för förbränningsbaserade och behålla många processegenskaper samtidigt som man potentiellt kan minska växthusgasutsläpp.

Elbaserade lösningar, men framförallt induktionslösningar, kräver individuell anpassning till mängd, storlek och typ av stål. Exakt data på lösningar finns därför inte presenterade hos leverantörer av elbaserade lösningar då de inte vill presentera siffror de sedan inte kan leverera. Leverantörer ber istället om att bli kontaktade för skräddarsydda lösningar, och samtliga som kontaktades drog sig för att gå in i hypotetiska situationer. Vad det berodde på exakt kan jag inte svara på men det var ofta som hänvisningar gavs till personer som var på semester, då studien som sagt utfördes under 4 veckor mitt under sommarperioden. För en tydligare helhetsbild av nuläget bör denna litteraturstudie kompletteras med intervjuer av företagsrepresentanter.

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Bilaga 1 Komplett lista över databaser som täcks av LTUs sökmotor.

Academic Search Elite
Academic Search Index
ACS Legacy Archives
AES E-Library
AIAA All E-Archives
AIP Digital Archives
Allen Press Journals
AMED - The Allied and Complementary Medicine Database
American Association for the Advancement of Science (AAAS)
American Doctoral Dissertations, 1933 - 1955
American Geophysical Union Digital Library
American Institute of Physics Other Society Titles (BIBSAM)
American Mathematical Society (AMS) Journals
American Meteorological Society Free Backfiles
American Physical Society (BIBSAM)
American Society of Civil Engineers
American Society of Mechanical Engineers (ASME) Package 2A: Journal Archives
American Society of Mechanical Engineers (ASME): Package 2: All Transactions Journals (2000-Present)
AMS Books Online (Open Access)
ASCE Conference Proceedings
ASM Materials Information Online
ASTM Journals
ASTM Standards and Engineering Digital Library
Begell House Journals
Bentham Open - Journals
BioOne Open Access
Books at JSTOR: Open Access
Cambridge Books Online
Cambridge Journals Online (BIBSAM)
Carl Hanser Verlag Open Access Journals Archive
CINAHL with Full Text
Cochrane Library (Wiley)
CRCnetBASE
DawsonEra eBooks
De Gruyter
DigiZeitschriften (Open Access)
DOAB Directory of Open Access Books
DOAJ: Directory of Open Access Journals
eBook Academic Collection (EBSCOhost) - Worldwide
Ebrary Nordic Collection
EBSCO Discovery Service
EBSCO eBooks
EBSCO eBooks
EBSCO Open Access Journals
EconLit (EBSCO)
Emerald Backfiles
Emerald E-Journals Premier (BIBSAM)
EMIS: Electronic Library of Mathematics

Ergonomic Abstracts
ERIC (EBSCO)
Free Access Journals (HighWire)
Fri e-tidskrift
Gallica (Bibliotheque Nationale de France)
GeoRef In Process
Geoscience e-Journals
HighWire Press
Hindawi Open Access Journals
IAMCR: International Association for Media and Communication Reseearch Open Access
IEEE Xplore Journals
IEEE/IET Electronic Library (IEL)
IMechE Collection with Archive
Inderscience Enterprises (BIBSAM)
INFORMS PubsOnline
InfoSci Journals
IngentaConnect
InTech Open Access
IOPscience extra
IOS Press E-Journals (BIBSAM)
IWA Publishing Online Journals
Journals for Free
Journals for Free
J-STAGE Journals (Open Access)
JSTOR - National Council of Teachers of Mathematics
JSTOR Arts & Sciences I Archive Collection
JSTOR Arts & Sciences II Archive Collection
JSTOR Arts & Sciences III Archive Collection
JSTOR Arts & Sciences IV Archive Collection
JSTOR Current Collection
JSTOR Free Early Journal Content
JSTOR Health & General Sciences Archive Collection
Library, Information Science & Technology Abstracts (LISTA)
Literary Reference Center
Mary Ann Liebert Journals (BIBSAM)
Massachusetts Institute of Technology (MIT Press)
Mediearkivet
MEDLINE (EBSCO)
MLA Directory of Periodicals (EBSCO)
MLA International Bibliography (EBSCO)
Nature Journals Online
Nature Journals Online (Open Access)
Nature.com Complete
Newswires
OAPEN (Open Access Publishing in European Networks)
OECD-iLibrary IEA Statistics
OECD-iLibrary Statistics
Optical Society of America (OSA) - Optics InfoBase
Oxford English Dictionary
Oxford Music Online

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Library, Information Science & Technology Abstracts (LISTA)
Literary Reference Center
Mary Ann Liebert Journals (BIBSAM)
Massachusetts Institute of Technology (MIT Press)
Mediearkivet
MEDLINE (EBSCO)
MLA Directory of Periodicals (EBSCO)
MLA International Bibliography (EBSCO)
Nature Journals Online
Nature Journals Online (Open Access)
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Springer eBooks (Engineering 2013)
Springer eBooks (Engineering 2014)
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Springer Online Archives Collection
SpringerLINK eJournals (BIBSAM)
SpringerMaterials
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Taylor & Francis
Taylor & Francis (BIBSAM)
Taylor & Francis Engineering, Computing & Technology Archive 2017
Taylor & Francis Informa Healthcare Journals (BIBSAM)
Taylor & Francis Open
The Journal of Orthopaedic and Sports Physical Therapy (JOSPT)
Trans Tech Publications
Ubiquity Press Open Journals
Universitetsforlaget Idunn (BIBSAM)
Vandenhoeck & Ruprecht Journals
Wiley Major Reference Works
Wiley Online Library Backfiles
Wiley Online Library Business and Management Backfiles
Wiley Online Library Free Journal Backfiles (formerly Blackwell Synergy)
Wiley Online Library Materials Science Backfiles
Wiley Online Library Numerical Engineering Backfiles
Wiley Online Library Online Books
Wiley Online Library Open Access
Wiley Online Library Polymer Backfiles
Wiley Online Library Tribology Backfiles
WorldSciNet Open JournalsZentralblatt MATH restricted access resource
Zeteo restricted access resource

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JERNKONTORET

Box 1721, 111 87 Stockholm · Kungsträdgårdsgatan 10
Telefon 08-679 17 00 · Fax 08-611 20 89
E-post office@jernkontoret.se · www.jernkontoret.se