Furnace Tapping 2018, Edited by J.D. Steenkamp & A. Cowey,
Southern African Institute of Mining and Metallurgy, Kruger National Park, 14–17 October 2018

Tapping procedures in silicon production, and the role of female tapping operators

M.B. Folstad[1], M.Tangstad[1], E. Ringdalen[2], R. Fredriksli[3], and S. Dalum[3]

[1]NTNU
[2]SINTEF
[3]Wacker Chemicals Norway Holla Metall, Norway

This paper outlines the main work routines of tapping operators on a Norwegian silicon production plant. The work is based on information from tapping operators at Wacker Chemicals Norway Holla Metall. With the improvements over the past 30 years with automated tapping equipment, the number of female tapping operators has increased.

Keywords: tapping, silicon production, women operators.

INTRODUCTION

Molten silicon (Si) is produced industrially by carbothermic reduction of quartz (SiO_2) in a submerged arc furnace. Tapping is the process of draining liquid silicon from the furnace and takes place through a channel connected to the interior of the furnace via the tap-hole. Figure 1 shows an overview of the tapping process on a submerged arc furnace (Kadkhodabeigi, 2011). The processes that take place inside a silicon furnace are presented in Figure 2. The tapping of the silicon plays an important part in silicon production – to obtain an optimum production yield it is essential to secure good draining of the silicon from the furnace. Accumulated silicon may disturb the process by reacting with SiO_2, which increases the amount of silicon monoxide (SiO) gas and thus decreases the silicon yield. A successful tapping process contributes to the stability of furnace operation and high productivity. (Schei, Tuset, and Tveit, 1998).

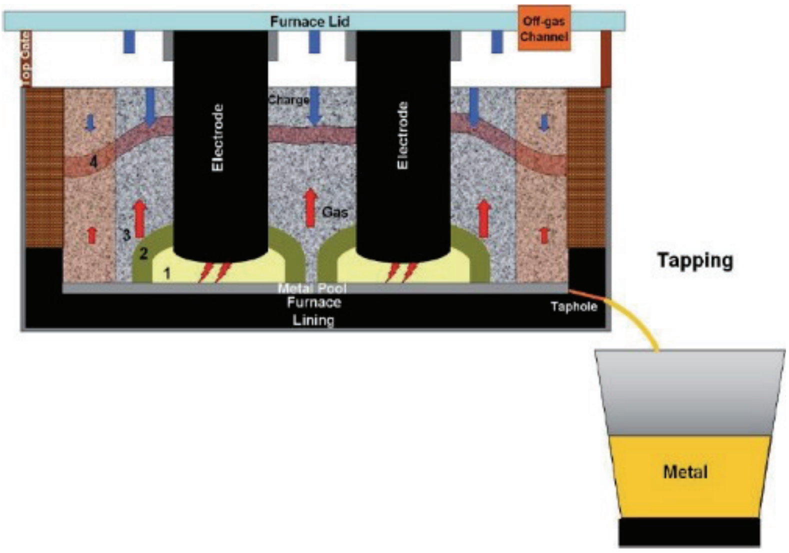

Figure 1. Schematic drawing of the tapping process in submerged arc furnaces (Kadkhodabeigi, 2011). The runner and furnace hood system are not included.

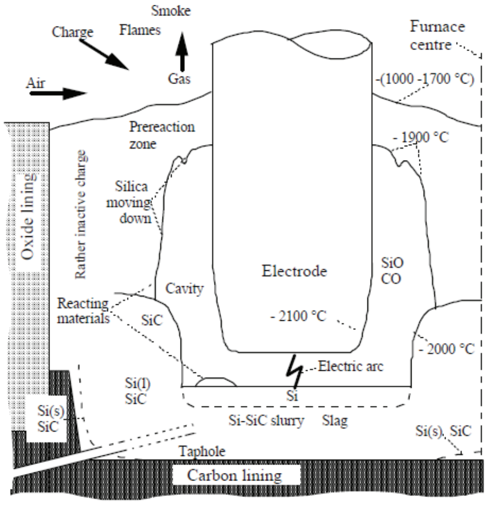

Figure 2. The distribution of different reaction zones and materials in a submerged arc furnace producing silicon shortly before it is ripe for stoking (Schei, Tuset, and Tveit, 1998).

The tapping operators have to control the flow of molten silicon at a temperature above 1500°C. Several challenges are associated with this critical process, and are summarized by (Tveit *et al.*, 2014):

- Good drainage of silicon from the smelting furnace is a prerequisite for stable furnace operation and optimal silicon yield. If silicon is allowed to accumulate in the furnace over time, it will react with either carbon or silicon dioxide, which in turn will disturb the furnace process and reduce the silicon yield (Schei, Tuset, and Tveit, 1998).
- Utilizing the right kind of tapping equipment is important to obtain the correct product quality. The tapping process may also have an adverse effect on the production yield and the total revenue.
- The tapping area has several safety challenges. Operators are in close proximity to molten silicon, high temperatures, moving equipment, and complex logistics. The risk of burns and crush injuries is high unless preventive action is taken.
- The tapping process performance affects the working environment. The tapping area is one of the largest sources of internal air pollution at the smelting plants.

A tapping operator's role is associated with hard physical work, and was previously performed only by men. However, the tapping process has seen improvement over the past 30 years and simple automated tapping equipment has been introduced. Trucks and cranes do most of the material transfer and most of the tapping equipment is connected to an automated multi-tool platform. Due to increased automation, and as the opinion on the plants changes, there are more female tapping operators. Wacker Chemicals Norway Holla Metall, a silicon plant located 90 km southwest of Trondheim, introduced their first female tapping operator in 2010. Today it is normal for women to make up 10–15 % of the tapping operators in Norwegian silicon plants.

THE MAIN WORK ROUTINES FOR A TAPPING OPERATOR IN SILICON PRODUCTION

Maintaining the Tap-hole

A side view of tapping from a submerged arc furnace is presented in Figure 3 (Kadkhodabeigi, 2011). Tapping can be done either continuously or discontinuously. In continuous tapping, the tap-hole is open at all time, except for maintenance stops or unwanted incidents, damage to equipment *etc*. In discontinuous tapping the tap-hole is closed and opened at specified time intervals. This article focuses on continuous tapping, which is applied on most silicon production furnaces. There are several tap-holes located around the furnace body, but only one tap-hole is open for tapping at a time. The furnaces are rotating, and the designated tap-hole will be changed to a new tap-hole as the first tap-hole rotate away from the tapping area. Many plants close the open tap-hole once every day to maintain a clean and properly functioning tap-hole. The open tap-hole should also be changed every three to five days, depending on the rotation speed of the furnace. It is the responsibility of the tapping operators to close and open the tap-holes during operation, as well as to keep the flow high. A mud gun is used to close the taphole by injecting special clay, which hardens and binds to the furnace wall. The mud gun may be part of a multi-tool platform, or it can be installed on a truck. In both cases, closing of the tap-hole is performed with an automatic system and female tapping operators have no problem executing the work. Opening a tap-hole is done with a drill connected to the multi-tool platform. Every opening requires a new drill bit, and the tapping operators experience the lifting and changing of drill bits as heavy work. Female tapping operators prefer to do this as a team of two, or may ask for help if they are struggling. Drilling is continued until silicon flows from the furnace.

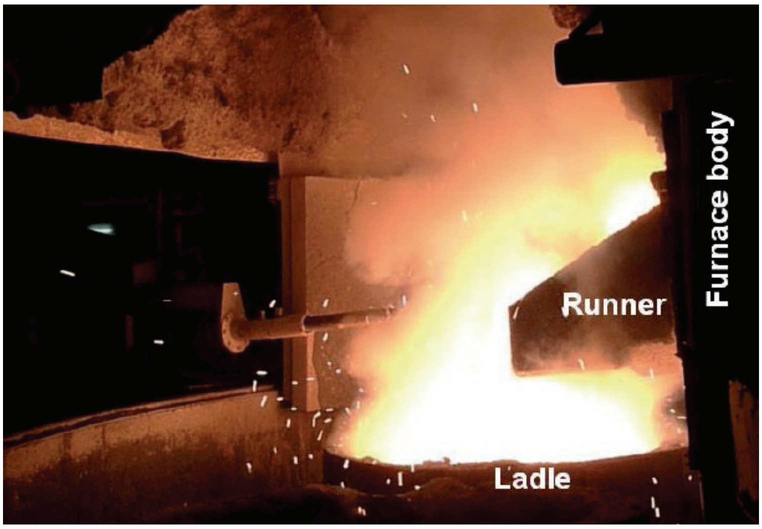

Figure 3. A side view of tapping of silicon melt from a submerged arc furnace. A very high temperature melt flows into the ladle from the furnace hearth (Kadkhodabeigi, 2011).

Continuous tapping should ideally give an even flow of metal that equals the production rate. However, in reality the tapping rate decreases in some periods and the tapping operators need to remove obstacles to maintain a good flow. The obstacles are is typically viscous slag or silicon carbide (SiC) particles from inside the furnace that accrete and restrict the flow of silicon through the tap-hole. There are three main methods for removing obstacles:

- Soaked wooden poles in a stoking unit connected to the multi-tool platform. The tapping operators feed the stoking unit with the soaked wooden poles and guide them into the tap- hole. The high temperature evaporates the water and the expansion force pushes any solids out from the tap-hole.
- Blowing of oxygen through iron or aluminium lances. Any solids on the furnace wall will then either melt or soften, and be removed. As the temperature in the tap-hole exceeds the melting temperature of iron (1535°C) and aluminium (660 °C) (Aylward and Findlay, 2008), the lances are consumed and the tapping operators need to supply and connect more lances to continue blowing.
- Chiseling/penetrating the tap-hole with powerful mechanical equipment.

It is the tapping operators' task to decide which method to use. None of these methods requires more physical strength than a female tapping operator can handle. The multi-tool platform is fully automated and is controlled with a separate controlling device. The manual work consists only of supplying wood poles and lances.

Work Routines

During tapping, a ladle is placed under the tap-hole and fills up with silicon and some tapping slag. Figure 4 shows a ladle used in industrial silicon production. The flow rate of metal in continuous tapping is lower than in discontinuous tapping, which gives time for refining of the silicon melt by purging a mixture of oxygen and air into the ladle while tapping commences. A sufficient gas pressure is important to ensure good stirring of the melt to prevent solidification. The tapping operators control the gas pressure according to the company's guidelines. Adjustments are done according to variations in the analysis of the tapped silicon.

Figure 4. A typical ladle used in silicon production plants. A frame placed on rails holds the ladle.

In every ladle, the tapping operators add quartz (SiO_2) to accelerate the refining process and to prevent tapped silicon from oxidizing to SiO_2. Silicon fines are added if it is necessary to decrease the temperature of the melt in the ladle. The desired temperature of the melt during tapping is > 1550°C, and it is the tapping operator's responsibility to control the temperature. Addition of quartz and silicon is done with a crane, which is controlled with a separate device. Handling the crane requires great accuracy and experience, but in this task there is no difference between male and female operators.

The ladles are held on frames placed on rails, as shown in Figure 4, which enables trucks to move the ladles to the desired position. When a ladle is full, the tapping operators use trucks to replace the full ladle with an empty one. It is important to perform this process correctly. Failure to do so can cause serious accidents, since the molten silicon has a temperature above 1500°C. During tapping, there is always a second, empty ladle connected to the ladle under the tap-hole. The truck pushes the empty ladle and drags the full ladle so that the empty ladle is placed under the tap-hole. It is important to run the truck smoothly to avoid splashing of melt, and to place the empty ladle correctly under the tap-hole. It is also important to use an appropriate speed to avoid spilling melt on the floor. If the ladles sidetracks, the tap-hole must be closed immediately and the furnace shut down. A skilled tapping operator reduces the risk of potential accidents and contributes to a safe working environment.

After the refining process, the silicon is poured from the ladles. This is done when the temperature of the melt is around 1500°C. At this temperature, the slag will have a higher viscosity than the silicon, and it is therefore less likely that the slag will follow the silicon to the casting bed/plate. The liquid silicon is cast either in beds or in plates. A crane lifts the ladle to the emptying station. As both slag and silicon, in addition to solid lumps floating on the top of the melt, are present in the ladle, the emptying process requires great accuracy and careful handling by the tapping operator so that only silicon flows into the casting bed/plate. A good control of the crane is essential to avoid slag in the silicon. Slag is removed from the ladle with a roundel of steel which skims off the slag. The roundel is machine-driven and the tapping operators control the movement of the roundel using joysticks.

Refining Process

As mentioned previously, the silicon melt is refined by gas purging from the bottom of the ladle during continuous tapping. When the ladle is full, the refining process is completed in the refining station. The tapping operators measure the temperature and take a sample of the silicon in the ladle. At some plants, this is done with automatic equipment, but most plants still use manual equipment. The tapping operators dip a long steel pole connected to the sample collector/temperature sensor into the melt. The pole can be somewhat heavy to handle, but females have no problems executing the work if they have mastered the correct technique. The silicon samples are then analysed in the operating laboratory to obtain the percentages of various elements in the metal. In silicon production, only the aluminium (Al) and calcium (Ca) levels are adjusted by refining. Other important elements are controlled by selecting sufficient pure raw materials. From the test result, a computer program calculates the remaining refining time and whether any Al lumps should be added. It is often necessary to add lumps of Al just before casting to obtain the desired quality of silicon. The tapping operators add the lumps manually with a shovel. This is also considered as heavy work, and correct technique is of great importance to avoid injuries. The female tapping operators can perform this task in several rounds by adding smaller amounts of Al lumps at a time.

VIEWS FROM FEMALE TAPPING OPERATORS

From the female tapping operator's point of view, the difficult part of the job is not the physical work – it is rather the decisions that has to be made based on experience, for example when and which method to use to remove obstacles in the tap-hole. In a typical working day, tapping operators do not experience any limitations due to the fact that they are females. As a tapping operator you are never alone at work, and tapping operators from different furnaces at the plant cooperate if the work is heavy. If any automated equipment is out of action, the female tapping operators would not have any problems executing the work manually. The female tapping operators also feel that they contribute in a positive way to the working environment.

CONCLUSION

Tapping is a very important part of silicon production, and the plant depends on skilled operators in the tapping area to maintain a stable production process. Previously, as this work was considered as heavy physical work, only men worked as tapping operators. Today most of the work is performed with automated equipment, which makes it possible for women to work as tapping operators. The female tapping operators do not experience any physical limitations in their work, but rather feel that they contribute in a positive manner to the running of the furnace.

ACKNOWLEDGEMENTS

The authors would like to thank Wacker Chemicals Norway Holla Metall for the contributions to this paper. The Norwegian Ferroalloy Research Association (FFF) and the Norwegian Research Council (NRC) are appreciated for their financial support through the KBN project Controlled Tapping, project no. 267621.

REFERENCES

Aylward, G. andFindlay, T. (2008). *SI Chemical Data*. 6th ed.. Wiley, Australia.

Kadkhodabeigi, M. (2011). Modeling of tapping processes in submerged arc furnaces. Doctoral thesis, NTNU, Trondheim, Norway

Schei, A., Tuset, J.K., and Tveit, H. (1998). *Production of High Silicon Alloy*. Tapir Academic Press, Trondheim.

Tveit, H., Andersen, V., Berget, K.H., and Jensen, R. (2014). The tapping process in silicon production. *Proceedings of Furnace Tapping 2014*, Muldersdrift, South Africa, 27-29 May 2014. Southern African Institute of Mining and Metallurgy, Johannesburg. pp. 147-156. https://www.saimm.co.za/Conferences/FurnaceTapping/147-Jensen.pdf.

Prof. Merete Tangstad
NTNU
1989-2000: Elkem – FeMn and SiMn research and operation
2000-2004: Eramet – FeMn and SiMn research
2004 – td: professor at the Norwegian University of Science and Technology, Department of Material Science and Engineering with a focus on FeMn/SiMn production, Si/FeSi-production and solarcell silicon refining