Application of The Channel Induction Furnace For Melting Aluminum

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SUMMARY

Based on present and future energy and metal prices, the channel induction furnace constitutes the most economic melting unit in Europe. This may vary from country to country, depending on type and availability of energy. The channel induction furnace is particularly suited for scrap melting operations, and preferably for melting light-gauge scrap with very low melting losses. This paper discusses one example to illustrate the application of channel induction furnaces.

INTRODUCTION

Aluminum scrap can be processed in various melting units:

- direct-heated furnaces (gas or oil-fired) with heat recovery facilities
- induction furnaces, channel or crucible type.

The choice of unit is determined primarily by availability and form of energy and production costs.

The present supply of fuel calls for us to re-evaluate its future availability. It is to be expected that rising fuel prices will also entail an increase in the price of substitute energy—electricity—in which case thought must be given above all else to the optimum utilization of that form of substitute energy. Here, the induction furnace offers a high-power input utilization factor, since heat is generated by electrical induction directly in the bath.

Rising labor costs in the industrialized countries and higher metal prices oblige us to remelt even low-grade, light-gauge scrap and to employ a melting unit where the essential factors that determine processing costs are low, namely energy costs, melt losses, maintenance costs, and labor costs.

BASIC OPERATION

Meltdown Rate and Furnace Capacity

The meltdown rate is determined by the installed capacity of an inductor and the number of inductors mounted on the furnace. One, two, four, or six inductors may be fitted, depending on the furnace holding capacity. The meltdown rates currently used in production operations are up to 2 t/h* per inductor. Accordingly, the following guide values are obtained:

Holding Capacity, tons Al	Max. Number of Inductors	Max. Meltdown Rate, t/h
>12	2	4
>18	4	8
>30	6	12

*All tons are metric tons.

The specified holding capacities are the minimum capacities required at present on design grounds to permit mounting of the stated number of inductors.

Charging

Materials such as saw and scalper chips and baled, shredder and extrusion scrap can be charged using vibratory chutes on a virtually continuous basis into the induction furnace. Bulky material such as pigs and sows, rolling mill, and extrusion scrap can also be charged via vibratory chute. Batch charging is possible. In contrast to the fuel-fired furnace, charging operations do not interrupt the meltdown procedure or cause heat losses through opening the furnace cover. In addition, misruns of continuously cast blooms and billets can be charged without difficulty in full casting length into the channel furnace.

Change of Alloy

The channel induction furnace is a flexible unit, in that it does not necessarily have to be completely emptied in the case of frequent alloy changes. The furnace shape is designed to permit alloy change using a minimum hot heel. For example, the hot heel in a 50-t furnace is only 10 t to enable meltdown operations to be carried out at full power. This heel can even be reduced to 7 t if the pinch effect is accepted into the bargain and melting carried out at reduced power.

Alloy Production, Bath Mixing

The production of casting alloys with a high proportion of silicon, and forgeable alloys containing high-segregating components such as lead, calls for intimate mixing of the bath. A fuel-fired furnace requires either elaborate stirring equipment or cost-intensive operating personnel. The practice also involves loss of energy and production time.

The channel furnace, on the other hand, possesses an automatic stirring effect, since the inductors are arranged at angles on the furnace floor to provide uniform distribution of heat over the bath cross section. At the same time, the directed-flow inductors are designed as flow heaters. The flow is, however, so rated that in a full furnace the bath surface remains intact, thus preventing increased oxidation of the melt.

Figure 1 shows the principle of the channel induction furnace.

Dross Removal

The modern furnace features two tilting axes, axis no. 1 for pouring operations and axis no. 2 for dross removal in the opposite direction. Here, the furnace is tilted to such an angle that dross can be withdrawn by means of a skimmer attached to a forklift truck. The average time for dross removal is 15 min.

ENERGY CONSUMPTION AND ENERGY BALANCE

The channel induction furnace has a high installed capacity utilization factor.

Using a 50-t channel furnace with 3400-kW power input as an example, the full meltdown power is started directly at the beginning of charging operations. In contrast to the fuel-fired furnace, charging can be effected continuously during meltdown so that thin-gauge material is submerged in the molten heel of metal extremely rapidly.

Nonproductive times such as dross removal, metal pouring and other operations account for only 10% of the specified tap-to-tap time, i.e., power availability in the meltdown phase is 90%. These short idle times are also reflected in a low total energy consumption.

Depending on furnace size and power input, the channel induction furnace offers energy utilization factors of between 71% and 75%. Figure 2 shows as an example the energy balance of three different furnaces in the meltdown phase. The fuel-heated furnace, a modern round unit with air preheater, has a thermal efficiency factor of 42%,[8] while the channel induction furnace has 73%. Using clean scrap grades, where flue gas extraction can be neglected, thermal efficiency factors in the channel induction furnace can be as high as 80%.

Assuming a theoretical heat content in the melt of 320 kWh/t at 740°C, then approximately 450 kWh/t energy is required by the channel induction furnace for light-gauge material. This is, however, only the energy requirement for melting and bringing up to pouring temperature. Including losses from flue gas extraction operations and energy required for ancillary equipment, such as inductor cooling, and for idle times, during which the melt is mainly held at temperature, the total energy consumption comes to 475 kWh/t for a 16-t furnace and 460 kWh/t for a 50-t furnace.

Thermal and electrical losses in the inductors and power feed lines are dissipated by cooling water. This heat can be recovered in the form of hot water for showers and low-temperature heating systems. Operating experience shows that waste-heat recovery rates of up to 65% are attainable.

In the light of steadily rising energy prices, overall thermal efficiency will in the future be improved by the use of heat recovery installations. If the heat recoverable from cooling water, which is produced at a fairly constant rate viewed over the production time, is considered as a bonus, then thermal efficiency of the channel induction furnace will amount to 90%. At present-day fuel and energy prices, this suggests a reasonable capital payback time.

MELT LOSSES

Melting light-gauge scrap in the channel induction furnace involves substantially lower melt losses than in the fuel-fired furnace. To give an example: remelting foil packs or coils yields 1.5% melt losses in the channel induction furnace as against 13% in the fuel-fired furnaces.[2]

A major contributing factor to high melt losses is the dwell time of the material in the furnace atmosphere, as the water vapor formed by combustion also causes surface oxidation of the aluminum. This is an important factor, since the thinner the material the greater is its surface and thus the extent of oxidation; and this surface oxidation produces extremely high melt losses, since it forms a thick and relatively tough oxide envelope preventing the metal underneath from melting. It also retards drainage of metal from the oxide envelope; the metal droplets do not coalesce and are entrained in the dross. In 1977, Stewart, et al.[3] of Alcan Ltd. established that, for 0.5 mm gauge sheet in fuel-fired furnaces, increasing the meltdown time from 40 min to 105 min increased melt losses from 3% to 8%.

It is true that the metal yield, i.e., prevention of melt losses, can be improved in the fossil fuel-fired furnace by using fluxes. The ideal application is to introduce thin-gauge material into a sufficient quantity of fluxes. Fluxes increase the melting energy requirement, cause emissions, and must ultimately be disposed of — thus involving considerable cost. Hence, melt losses can be reduced only by cutting the meltdown time, and it is here that the channel induction furnace has its special advantages: thanks to its molten heel of metal, it guarantees immediate submergence of the thin-gauge material.

To appreciate the improved cost situation due to reduced dross formation, consideration must be given not only to the decreased melt losses but also to the improved foundry operations resulting from reduced dross handling problems. Here, however, we shall concentrate only on the value of metal losses. Assuming that the dross has a metal content

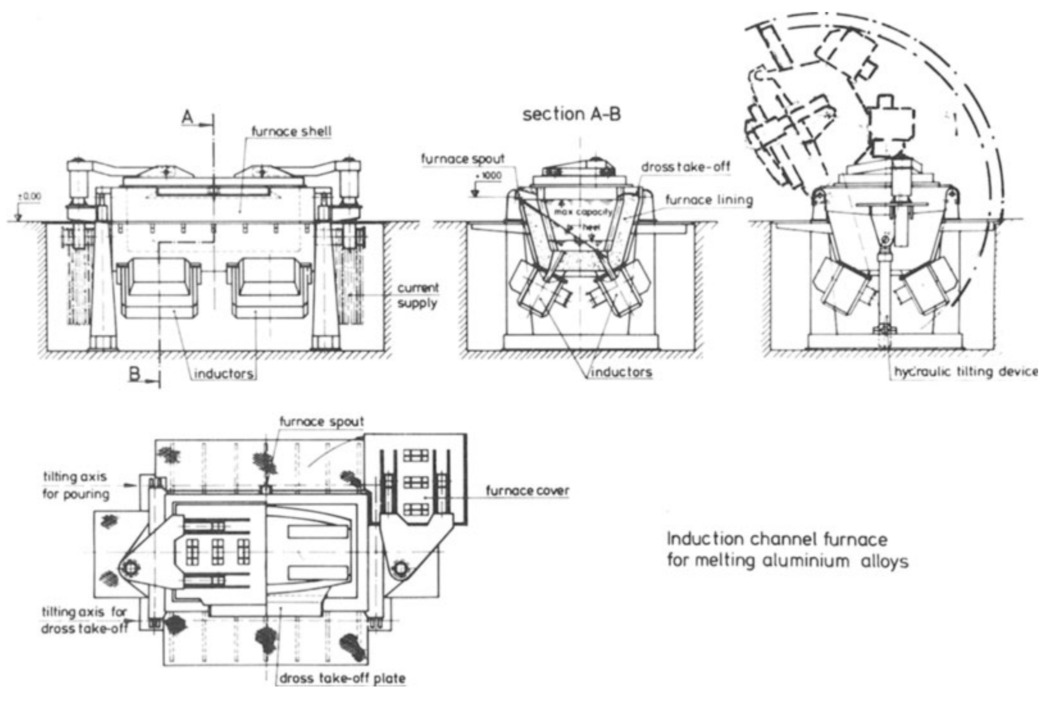

Figure 1. Principle of the channel induction furnace.

of approximately 70%, then the following picture is obtained:

Value of metal in the dross	approx. 2.90 DM/kg metal
Metal value of the dross	2.03 DM/kg dross
Market price of the dross	0.60 DM/kg dross
Loss	1.43 DM/kg dross

Reduction in dross formation using a channel induction furnace: 10% of charge, corresponding to 100 kg dross per ton of charge.

Saving: 1.43 x 100 = 143 DM/t metal charge.

In reality, substantially higher savings are achieved since handling, incidental material costs, and also melting costs would have to be taken into account as well. One production works cites costs at double this figure.[4] Accordingly, it is easy to calculate that investment in an induction furnace will have been paid back in less than two years.

PLANT MAINTENANCE

Electrical, hydraulic, and control equipment do not constitute major cost factors in normal plant maintenance. However, the channel induction furnace does involve ceramic costs for furnace hearth and inductor lining replacements.

Inductor Service Life and Replacement Time

The service life of an inductor depends on the installed capacity, the type of cooling system, the shape of the channel, and the type of ceramic lining. Service lives of 250 days are reported for air-cooled inductors rated at 250 kW, but of only 100 days for 400 kW ratings. In both cases, the metal throughput was approximately 1,600 t aluminum.[4] By improving the cooling effect and type of ceramic lining, it is possible for 400-kW inductors to attain life factors of 250 days and more with metal throughputs of 2,500 t/inductor. However, service lives of only 100 days are also not unknown. Another operating plant reports service life factors of 15-27 months.

Higher inductor ratings of 900 kW and more with production rates of 30 t/day per inductor, necessitating directed flow of the metal and intensive cooling, have not yet been in operation for any length of time. Initial experience showed that vigorous flow causes erosion in the vertical channels. Even though it was not necessary to clean the channels, the desired service life of the inductor was reduced. Further improvements have been made by slowing down the directed flow and by providing a more stable water cooling system, which gives hope for attaining service life factors of 12 months for the high-power inductors.

Nevertheless, one factor still remains: the care taken in lining, drying, and sintering operations. A service life of 250 days or 100 days is evidence enough. Short production downtimes for inductor replacement and reduced dependence on the workmanship of lining operations are required for high-performance melting units. Here, the wet ceramic compound versus the dry compound is at a disadvantage, since it requires very careful ramming to prevent the formation of layers, and then due to its water content must be just as carefully dried and sintered. In the case of dry ramming compounds, which are vibrated and more rapidly sintered, a furnace is nowadays ready for production within 12 hours, including inductor replacement. With wet compounds, downtimes can be as much as 14 days, depending on the degree of predrying.

Clogging of the Channels

This phenomenon occurs when oxides adhere to the channel walls causing reduction of the channel cross section. A lower meltdown rate is the result. In older furnaces with low inductor ratings (200-300 kW, for example), the vertical channels had to be cleaned several times a day using drills or chisels to regain their original size. Clogging of the channels is aided by three factors: the proportion of magnesium in the analysis, the proportion of finely divided scrap in the charge, and the type of flow in the inductor.

Experience has shown that the clogging tendency increases in line with the increased magnesium content in the melt.

When charging a high proportion of finely divided and thin-gauge material, the proportion of oxides and nonmetallic components increases automatically, and these can also be deposited on the channel walls. Whereas with inductors of older design heat exchange between inductor channel and bath was effected mainly by thermal buoyancy, modern inductors are designed for a directed flow of metal[6] and heat exchange is effected rapidly and without excessive overheating in the inductor channel by directed and defined flow pattern. The greater clogging tendency is countered by the flow of the metal.[6] Since the metal flow increases with increasing inductor rating, clogging must automatically be reduced. It is reported that inductors with ratings higher than 400 kW make the arduous daily task of cleaning the channel superfluous.[4]

Operating experience with thin-gauge material shows that cleaning work is not required with inductor ratings of 400 kW.[6] However, once a day each inductor is checked using a template. According to experience, this requires 5-7 min per inductor. This time of maximum 30 min/day affects furnace availability to only a negligible degree.

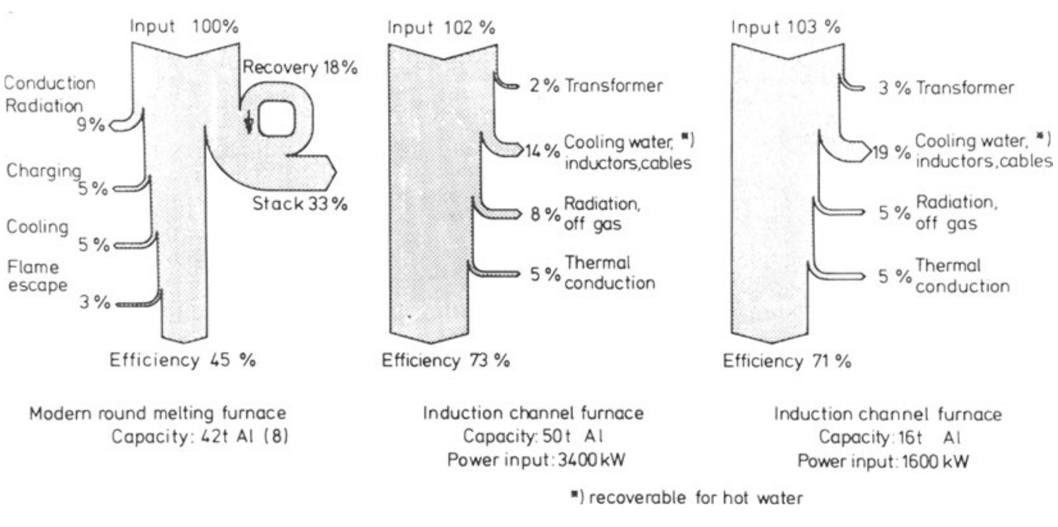

Figure 2. Energy balance in the meltdown phase. Note the efficiency factors of channel induction furnaces of 71-73%. Neglecting flue gas extraction when charging clean scrap grades, the thermal efficiency can be as high as 80%.

Table I: Service Life of Channel Furnace Hearth Ceramics

Ceramic Lining: Walls	Ceramic Lining: Bottom	Relining	Heat-up Sintering	Furnace: Downtime	Furnace: Lifetime
Bricks	Wet mix	3 weeks	14 days	6 weeks	5 years
Bricks	Dry mix	3 weeks	10 days	5½ weeks	4 years
Dry mix	Dry mix	1 week	2 days	2½ weeks	2½ years so far in operation (bottom replaced)
Gunning mix, wet	Gunning mix, wet	1 week	8 days	3 weeks	New plant

Service Life and Repair of Furnace Hearth Ceramics

The service life of the furnace hearth ceramics must be viewed in two parts:

- the furnace walls, whose service life is influenced by careful cleaning, and
- the furnace bottom, whose service life is affected by the type of charging material.

Generally speaking, the walls have longer service lives than the bottom, which is occasionally damaged by the charging of heavy scrap pieces. Partial repair is then necessary. Here, the ceramic material gains in importance with its short relining and drying times and, above all, easier repairability. To date, ramming compounds are generally used for lining the walls of small- and medium-size furnaces, whereas refractory bricks are used on an almost exclusive basis for the larger melting furnace. Although the bricks are highly wear-resistant, relining work takes a relatively long time. Furnaces have also been relined with dry compounds, which have extremely short lining and sintering times. However, these compounds have a high thermal conductivity, which in turn calls for thicker layers of insulation. With good insulation, this ceramic lining is more costly.

Table I gives the necessary downtimes for various types of lining.

Lining with refractory gunning material would appear to be the optimum solution at present, since it combines the advantages of rapid furnace reavailability (approximately 3 weeks) with rapid repairability permitting easy partial repairs.

The ceramic lining has been in operation for several months and to date has not yielded any negative results.

METAL QUALITY

Melting in the induction furnace has genuine advantages over the fuel-fired furnace. For instance, the content of hydrogen and nonmetallic inclusions is substantially lower.[4, 10]

The directed flow in the inductors generates an extremely favorable stirring effect, which in turn ensures uniform temperature and uniform temperature control, and rapid bath mixing and simple alloy production.

EXAMPLE OF CHANNEL INDUCTION FURNACES IN A MODERN CONTINUOUS CASTING SHOP

In this example, aluminum scrap is remelted and cast into extrusion billets and rolling ingots in a production works. The daily production rate, 100-120 t, is attained in three-shift operation using:

- 1 channel induction furnace as melting unit
- 1 channel induction furnace as holding and casting furnace
- 1 liquid metal treatment facility
- 1 vertical DC casting machine

The personnel requirement is three operators per shift.

Input Material

- Pigs and sows weighing up to 2,000 kg each
- Off-casts in the form of rolling and extrusion billets from in-works production in lengths up to 6.5 m
- Home scrap from extrusion and rolling operations
- Baled scrap, baled foils
- Saw and scalper chips

Charging

The scrap material is transferred in 8-10 t buckets to a vibrating conveyor for charging into the furnace. The vibrating conveyor is of the traveling type and located in the vicinity of the furnaces so that material can also be charged into the holding furnace as and when required.

Melting Furnace

The melting furnace, designed as channel induction furnace, has a total holding capacity of 50 t and a useful pour-off weight of 40 t maximum. The meltdown power is produced by four inductors mounted at defined angles on the furnace floor with a total connected load of 3,400 kW. Each inductor features its own tapped transformer for individual control operations.

In the event of failure of one inductor, the others hold the hot heel at temperature while the faulty inductor is being replaced. The furnace is again ready for production operations after a period of 12 hours. The molten metal is poured out through the furnace bearing and can be transferred at zero gradient to the holding furnace at the rate of 4 t/h. The holding-and-casting furnace also accepts the melt through the furnace bearing. This enables the metal to be returned to the melting furnace if required, likewise at zero gradient.

Holding-and-Casting Furnace

The casting furnace is similar in design to the melting furnace. The installed capacity of 1,600 kW, corresponding to a melting rate of approximately 3.5 t/h, is handled by two inductors. This furnace is used for bringing the melt to casting temperature and also for melting additional alloying metals when complicated alloys are required, the basic alloy being processed in the melting furnace in such cases. The holding furnace is also capable of accepting scrap charges. When operated at reduced production, it can also act as a melting furnace.

Melting and holding furnace are connected with each other and with the continuous caster by a system of launders. This permits the continuous caster to be fed from either furnace with the level of metal being the same over the whole distance from furnace to caster.

Figure 3 shows the setup of the overall plant with the two furnaces and the DC caster.

DC Casting

Level casting from the casting furnace is achieved using a control system to maintain the level of metal in the tundish and launder constant within close limits. The metal flows underneath a closed oxide skin from the furnace chamber to the tundish in the DC caster. The furnace tilting speed is automatically controlled in extremely fine stages.

The continuous casting machine is equipped with exchangeable casting equipment and is capable of producing strand lengths of 6.5 m with casting weights of up to 50 t for various production schedules.

Protection of the Environment

Since oily scrap is also melted in addition to dry materials, precautionary measures are adopted in order to comply with German air pollution control regulations. Both furnaces are equipped with hydraulically operated hoods to which the exhaust fan and offgas cleaning system are connected. The offgas system handles all gases formed in the furnaces and metal filters.

CONCLUSION

Due to its optimum energy utilization factor and very low melt losses, the induction furnace constitutes the most economic melting unit especially for processing thin-gauge scrap.

Increasing quantities of this class of scrap on international markets and rising energy prices will necessitate, with variations from country to country, the changeover from conventional fuel-fired furnaces to induction-heated furnaces.

Although the meltdown rate is still 2 t/h per inductor, or 7-11 t/h per furnace, developments including ceramics and inductor design improvements will in the future allow for higher meltdown rates that will come close to the figures for present-day fuel-fired furnaces, e.g., 20 t/h.

Given the same tap-to-tap time, the induction furnace as compared with the fuel-fired furnace has a higher meltdown power availability (90%) and plant availability of more than 90%. It can therefore attain the same production capacity with a lower hourly meltdown rate.

Compared with the crucible induction furnace, the channel induction furnace still offers the advantage of large holding capacities that are easy to cope with from the design viewpoint and can be built in sizes of 50-100 t and more.

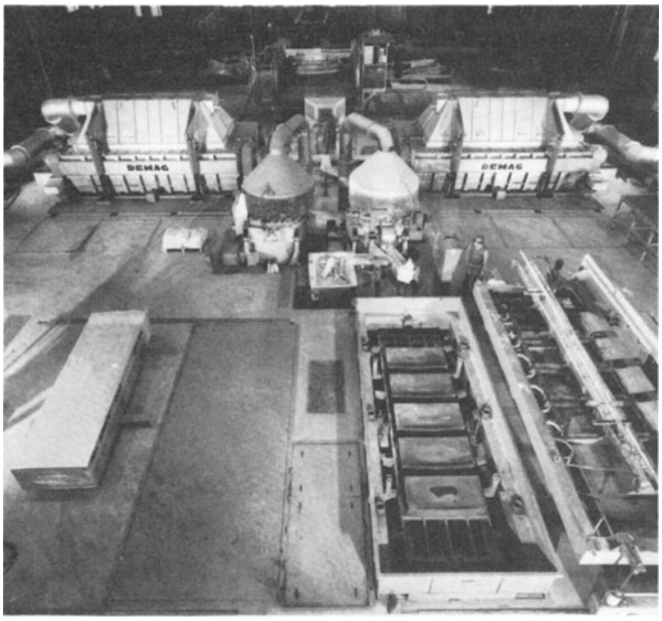

Figure 3. Aluminum melting and casting plant for a daily production of 100-120 t, with one 50-t channel induction melting furnace, one 50-t channel induction holding furnace, and one DC-casting machine for billets and slabs. Note that the casting machine can be fed by both furnaces at the same liquid metal level.

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