The Melting, Holding and Pouring Process – Energy and Process-Related Aspects

W. Schmitz
OTTO JUNKER GmbH, Simmerath, Germany

D. Trauzeddel
OTTO JUNKER GmbH, Simmerath, Germany

ABSTRACT

Process engineering requirements on the melting and pouring process, and particularly

- adhering to close metal composition and temperature tolerances;
- ensuring a timely supply of appropriate amounts of pourable metal;
  and
- balancing out of temporary fluctuations in molten iron demand;

impose high standards on the selection, design and operation of the individual sub-processes, from melting down charge materials to the controlled filling of moulds. Moreover, all of the foregoing must be done with a prime regard to attaining a high cost effectiveness and energy efficiency.

If we consider foundry energy inputs, it should be borne in mind that the melting and pouring processes account for more than 70 % of the foundry's total power consumption. The portion attributable to holding and pouring cycles is by no means insignificant. Looking at the average figures for cast iron, the energy consumption associated with the melting down of charge materials at 1,450 °C may well amount to 510 - 550 kWh/t, and in addition, almost 150 - 230 kWh/t are frequently needed for the subsequent holding, handling and pouring operations.

One should note in this context that more than 10 % of all moulding line disruptions are due to a lack of pourable metal, whereas approximately one-third of all moulding defects are attributable to flaws in the melting and pouring process.

From this angle, an evaluation of the technical alternatives for melting, holding, transferring and pouring the molten iron is presented, chiefly with regard to the use of induction-type furnaces.

OVERVIEW OF CAST IRON MELTING AND POURING PROCESSES

The general overview of alternative processes shows the variety of paths of the molten iron from the melting furnace to the pouring location (Fig. 1).

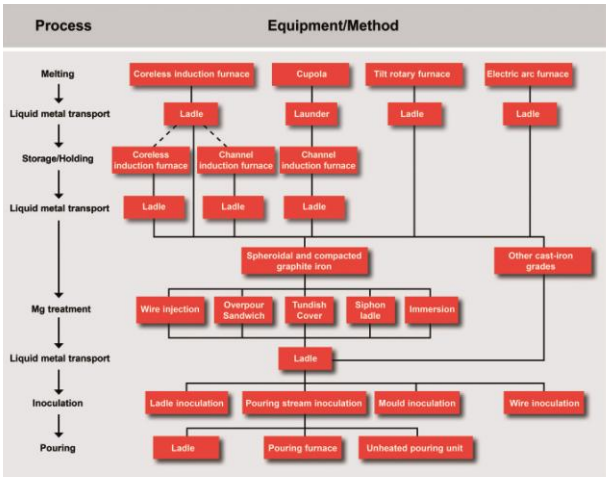

Fig. 1. Overview of cast iron melting and pouring processes.

As a matter of fact, cast iron materials are melted chiefly in cupola or induction-type furnaces today while rotary furnaces are rarely used in this context any more. In isolated cases, such as the grey iron foundry at the KAMAZ plant in Russia, electric arc furnaces are likewise employed as melting and holding units. The PSA foundry at Charleville (France) still relies on electric arc furnaces as well.[1]

It should be noted here that these processes not merely involve diverse technological sub-processes down to the pouring of melt into the moulds; the transport and distribution of the molten iron must also be taken into account. Long, and sometimes complex, transport routes and multiple melt pick-up points are no exception and call for an accurate planning and organization.

Increased demands on material quality, and especially the development of spheroidal graphite and compacted graphite iron, have markedly raised the importance of the metallurgical processes performed outside the furnace. This is particularly true for the magnesium treatment and inoculation of the molten iron. The design of these metallurgical steps, with their key impact on material quality, and their integration into the melting and pouring process chain merits special attention.

REVIEW OF THE SUBPROCESSES

MELTING

Equipment

An evaluation of the two alternative melting sources, the cupola and the coreless induction furnace, shall be limited to a comparison of some technical specifications and to a qualitative assessment in the present review (Table 1). A comparison in economic terms would not appear expedient in view of the prevailing regional and seasonal differences in energy and raw material prices and diverging views regarding the utilization options for certain scrap grades.

Table 1. Comparison of hot blast cupola and coreless medium-frequency induction furnace

Technical data	Hot blast cupola	Coreless medium-frequency furnace
Energy consumption	825 - 890 kWh/t	490 - 520 kWh/t (related to 1.450 °C)
Efficiency Melting furnace	47 - 44 %	79 - 75 %
Energy consumption Auxiliary equipment	20 - 70 kWh/t	5 - 10 kWh/t
Throughput	5 - 100 t/h	0.1 - 40 t/h (no upper limit)
Temperature variation	20 - 50 (90) K	5 K
Analysis variation		
C	0.5 - 0.7 % Delta C	0.1 % Delta C
Si	0.5 - 1.2 % Delta Si	0.1 % Delta Si
Slag quantity	40 - 100 kg/t	10 - 30 kg/t
Dust quantity	5 - 15 kg/t	0.06 - 1 kg/t
Metal losses	0.5 - 1.5 %	0.1 - 0.3 %
Si melting loss	10 - 30 %	5 - 10** %
S pick-up	0.12 - 0.15 % Delta S	0 % Delta S
C pick-up	1.0 - 2.4* % Delta C	adjustable
Rating* **		
Alloy change	2	5
Intermittent operation	2	5
Continuous operation	5	3
Chip melting	3	5
Contaminated charge material	4	3

* related to a C content in charge material of 1.0 or 2.0 %
** valid for high-silicon melts
*** 5 = very good, 1 = very unfavourable

From a process technology viewpoint, attention must be paid particularly to the variations in melt composition and temperatures, sulphur pick-up, and the flexibility deficits of cupola-type melting furnaces. This, in fact, is where the coreless induction furnace can boast its main advantages. Moreover, a cupola system produces notably more slag and dusts when compared to a coreless induction system. On the other hand, the continuous supply of large quantities of molten iron of the same grade is an advantage of the cupola.

As to the coreless induction furnace, the necessary addition of carburizing agents to charges containing major portions of steel scrap needs to be pointed out, as well as the fact that the unit cannot ensure a continuous melt supply. Instead, it provides a batch-type operation. The use of advanced tandem or DUOMELT-type furnaces or multiple coreless induction furnaces can, however, ensure a quite uniform supply of ready-to-pour molten iron. A concern voiced a few decades ago was that inductive melting might have a negative effect on nucleation conditions. These fears have by now proved unjustified, or else have become irrelevant thanks to modern inoculating methods.

Undeniably, modern hot-blast cupola systems have a higher direct energy consumption and lower efficiency than a coreless induction furnace. This picture is compounded by the higher energy demand of the auxiliary and ancillary equipment of a cupola furnace installation. Still, in terms of energy costs alone the cupola may still come out the winner if the specific coke price and electric power costs happen to compare that way.

Energy consumption

The optimized medium-frequency furnace technology keeps thermal and electrical losses to a minimum. The accurate determination of the charge weight, the calculation and supply of just the right energy input by the melt processor, and the precise computer-controlled furnace operating regime all contribute to an energy-saving melting process.

Whereas the energy demand for melting and superheating cast iron to a temperature of 1,500 °C is about 390 kWh/t, modern coreless induction furnaces need no more than 490 to 520 kWh/t including all thermal and electrical losses. On the other hand, consumption figures of 700 kWh and more are still recorded in day-to-day operating practice.

Here the question arises what are the reasons of this discrepancy. Let us take a look therefore at furnace operating regimes and their impact on power consumption.

Charge materials and make-up

An accurate calculation of the necessary charge make-up, based on material analyses, and a precise weight determination and metering of charge materials and alloying additives (including correction for set/actual value deviations) are basic prerequisites for minimising melting times and power needs. The use of clean and dry charge materials will definitely pay off, as the following examples show. If foundry returns are used which have not been cleaned from sand, converting the adhesive sand residue into slag will consume just as much specific energy as melting the iron, i.e., about 500 kWh/t. With a realistic amount of 25 kg of sand per tonne of iron this adds up to 12.5 kWh/t. Beyond that, of course, the quantity of slag is increased as well.

An even more decisive factor is rusty charge material. Its inferior electromagnetic coupling properties impair the transfer of melting energy and result in much longer melting times. The energy consumption and heat cycles for clean and highly corroded steel scrap, respectively, have been determined in comparative trials.[2] It emerged that rusty steel scrap took 2 - 3 times as long to melt and required a 40 – 60 % higher power input, as is evident from Table 2. Even assuming that these values reflect an extreme case, the negative effect of rusty charge material is quite severe. In addition, there are higher melting losses and greater slag volumes. Therefore, obviously, the use of rusty charge material should be avoided wherever possible.

Table 2. Effect of scrap quality on power consumption

Influence of scrap quality on power consumption at 1,500 °C

Charge material	Weight kg	Time min	min/kg	Energy kWh	Consumption kWh/t	Comparison of time %	Comparison of power %
Clean steel scrap	250	75	0.3	210	840	100	100
Rusty steel scrap	200	185	0.93	270	1,350	310	160
Rusty steel scrap	275	192	0.7	335	1,218	233	145

source (2)

The level of electromagnetic coupling achieved and hence, the power consumption of the charge, is a function, not least significantly, of the charge packing density. The heat cycle and energy consumption of the charge will thus vary with the packing density. The nature of this correlation has been examined with charges of different packing density in a high-power melting furnace operating under production conditions. The system employed for these trials had a capacity of 10 tonnes and a power rating of 8,000 kW at 250 Hz. The empty furnace was filled once with a charge of the specified composition, comprising pig iron, scrap castings, returns and steel scrap. No further charge material was added as the metal was heated to 1,380 °C. The power consumption was measured throughout this period. Different dimensions of the returns and steel scrap fractions made for packing densities in the 2 - 2.7 tonne/m³ range. It is evident from the trial results that a decrease in packing density from 2.5 to 2.0 tonnes/m³ caused a 25 kWh increase in power consumption (Fig. 2). Despite the additional cost and effort, it is therefore advisable to crush all too bulky returns to achieve a higher packing density. This will also facilitate furnace charging and eliminate the risk of material bridging in the furnace. The example of a U.S. foundry demonstrates that this practice can save money despite the costs caused by additional crushing operation.[3]

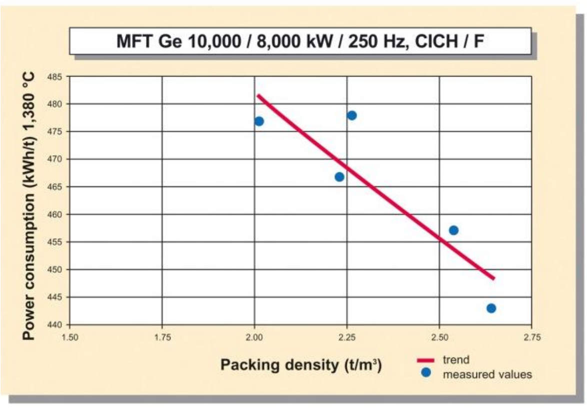

Fig. 2. Effect of packing density on power consumption (MFT Ge 10,000 / 8,000 kW / 250 Hz).

At the same time, a quick and continuous charging workflow is important when it comes to saving operating time and cost. A high filling level should be maintained at all times. Mobile shaker chutes and a bin accommodating the full charge are prerequisite to meeting this requirement. An extractor hood closely covering the chute will minimize radiant heat loss while ensuring that the furnace fumes will be reliably captured.

Chip melting

As foundries extend their level of vertical integration and take to machining their own castings, they increasingly find themselves with large amounts of chips on their hands – and what would make more sense than to try and use these chips in their own melting operation. Coreless induction furnaces, unlike other melting solutions, are highly suitable for melting down machine tool chips. Since grey cast iron is normally machined without coolants, these chips are dry and clean and can therefore be melted down without any pre-treatment. However, it should be noted here that the electrical contact between metal chips, despite their good packing density, is notoriously poor as a result of the small contact surface and surface oxidation. This is why the furnace should always be operated with a heel (> 40 %) when chips are melted. If the furnace is operated without heel, the power consumption for melting chips should be anticipated to be 50 kWh/tonne higher than for lumpy material. An increase in melting time must also be expected. If part of the charge material consists of chips, the solid material must be introduced first into the furnace and melted down. After that the chips are charged onto the developed heel of molten metal.

Carburising

Another factor reported to affect power consumption is the method of adding carburising agents[4,5]. The furnace will consume clearly more power if carburising agents are added into the molten metal bath after melting down rather than along with the solid charge material at the beginning. In-house experience indicates that this practice will consume about 1 to 2 kWh more per kg of carburising agent. This means that a realistic input of about 2 % of carburising agents will cause an additional consumption of up to 40 kWh per tonne of iron. An average of 70 kWh per tonne of iron for carburisation, as quoted in part of the literature, appears to be unreasonable. If the carburising agent is introduced into the furnace together with the other charge material, this should be done in controlled proportions so that the carbon content of the melt will not rise unnecessarily. An excessive increase in carbon concentration would cause premature crucible wear. It is also advisable to avoid the use of fine-grained carburising agents of low quality which tend to stick to the crucible wall. Local erosion effects would be the inevitable result. Furthermore, the input of silicon carriers should not take place until after carburisation is completed because increasing Si content in the melt decreases carbon solubility and also increases silicon losses.

Melting furnace operating regime

In theory, the most favourable operating regime would be one using the maximum available electric power and hence, high power densities. This rule has been conclusively confirmed by systematic trials. An operating mode of this type yields shorter heat cycles and lower thermal losses, thus reducing the consumption of electrical power. From the computed power diagram of a 12-tonne-furnace (Fig. 3) it is evident that the electric power consumption increases exponentially with decreasing power density since the percentage of energy required to make up for steady-state thermal losses will become disproportionately high when the power density is very low. This correlation is reflected in the ratio of holding power to rated power of the furnace. A comparison between a 6,000 kW melting operation and one with 3,000 kW (cf. Fig. 3) reveals a substantial power consumption difference of 20 kWh/t.

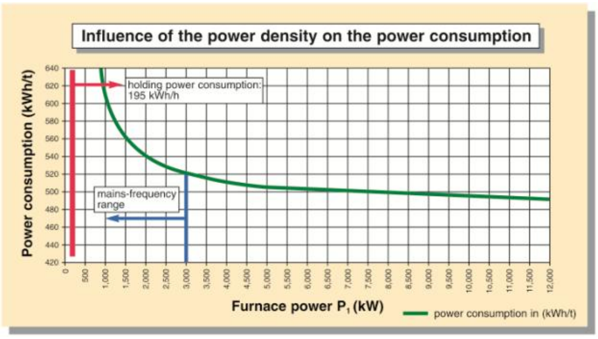

Fig. 3. Influence of the power density on the power consumption.

The use of medium-frequency technology makes it possible to operate the furnace without heel and to melt down small-sized charge material. Thanks to the superior electromagnetic coupling of solid charge material (although applicable only to cast iron and steel melting), the energy consumption in batch operation will be 8 % lower because a much higher coil efficiency is achieved up to the Curie point (Fig. 4). This advantage can be utilized by changing from mains frequency to medium frequency technology because mains-frequency furnaces are always started with a heel.

Energy is wasted, furthermore, by operating the furnace with its lid open for longer than necessary. The small heat losses, which are as low as 275 kW for a 15-tonne furnace for example, would thus rise to 600 kW which means an additional consumption of 6 kWh per minute of lid opening time.

Energy will also be "sucked off" unnecessarily if the exhaust system is run at full capacity even at times when no, or only little, flue gas is produced. In unfavourable circumstances this may increase the consumption of power by as much as 3 %. This corresponds to 15 kWh per tonne of iron.

Another issue is superheating, as a 50 K temperature rise will consume about 20 kWh per tonne of iron. The JOKS melting processor allows the final temperature to be maintained with an accuracy of 5 K, eliminating any unnecessary input of superheating energy.

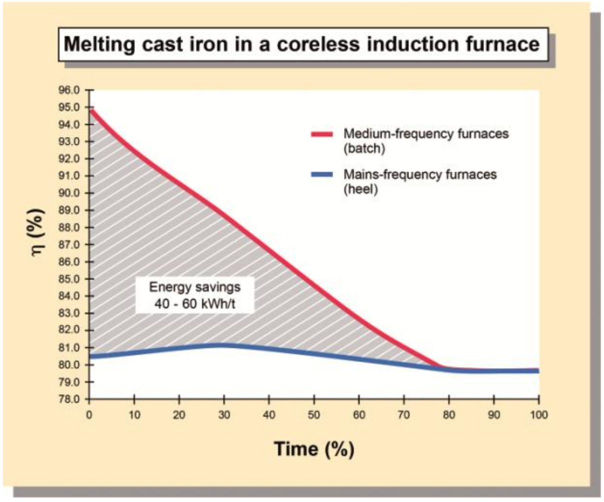

Fig. 4: Energy savings by switching from mains to medium frequency

Refractory lining

The wall thickness of the refractory furnace lining, which in cast iron melting systems will almost invariably be quartzite, always constitutes a compromise between good thermal insulation, adequate mechanical protection of the coil, and good electromagnetic coupling between the coil and the charge. Decreasing refractory thickness improves the coil efficiency and increases the power input but at the same time admits higher thermal losses through the thinner crucible wall. However, since coil losses exceed the thermal losses across the crucible wall nearly by the factor of 10, coil losses remain the dominant influence here. Studies have shown a substantial reduction in power consumption with decreasing thickness of the refractory lining[1]. With increasing furnace operating time and hence, progressive refractory wear, the power consumption will decrease by nearly 10 % over the first three weeks. Calculation of the change in coil efficiency reveals an increase of 3 % only (Fig. 5), assuming that a lining having an original thickness of 125 mm loses 30 mm of that thickness. It follows that this fact alone cannot explain the above-mentioned energy savings. In all probability, the increased power input into the charge and the resulting shorter melting cycle also contribute to this energy-saving effect. It might therefore make sense to consider eliminating excessively high "safety margins" on the thickness of the refractory lining with the aid of advanced crucible monitoring equipment such as the OCP optical coil protection system.

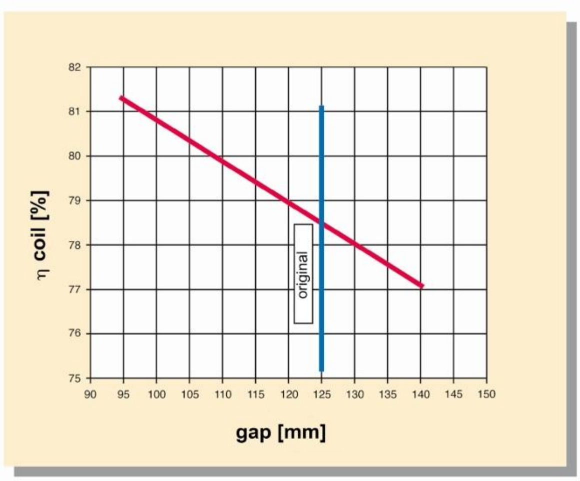

Fig. 5. Effect of lining thickness on coil efficiency.

Table 3 summarizes how an unfavourable furnace operating and control regime leads to significant extra consumption which in aggregate may well be as much as 200 kWh per tonne of iron.

Table 3. Extra consumption due to unfavourable management and operating regime

Energy Consumption
Melting of cast iron up to 1,500 °C
Medium-frequency furnace 8,000kg/8,000kW/250 Hz

		kWh/t
Melting enthalpy (theoretical)		**390**
Equipment	Thermal and electrical losses	126
Energy consumption for melting		**516**
Extra consumption for operating conditions		
	sand in charge material 25 kg/t	12.5
	rusty charge material	30
	low packing density of only 2.0 instead of 2.5 t/m³	25
	carburizing after melting, 20 kg/t	40
	melting with 50 % power density	20
	melting with heel	40
	unrestricted fume extraction	15
	holding for 20 min. with open lid	10
	unnecessary superheating by 50 K	20
Total extra consumption		212.5
Possible grand total consumption		**728.5**

Energy-saving coil

The largest portion of the energy loss is caused by the induction coil. In melting cast iron, for instance, coil losses amount to around 15 %. In the case of copper they account for almost 30 %. A further significant cut in energy consumption can therefore be achieved only by reducing the coil losses.

The ohmic losses across the coil depend chiefly on the current density, along with the material and coil temperature. The electromagnetic forces cause the current to be focused on a small area of the total coil cross-section, which results in a high current density and attendant high losses.

As reported, it has proven possible to devise a special coil design which enlarges the effective current-carrying surface area and thereby reduces losses[6]. In the case of non-ferrous charge metals the system can save up to 10 % energy. With ferromagnetic materials (cast iron and steel) the energy savings may amount up to 4 % because here the electromagnetic energy transmission is generally more efficient. This holds true even if conventional coils are used.

A feature worth noting is that this new coil can also be retrofitted into existing coreless furnaces. It is therefore suitable for upgrading projects as well.

Several years ago, a number of copper melting furnaces at Schwermetall in Stolberg (Germany) were equipped with this new coil type. Since that time, these coils have proven their merits in continuous operation[7]. The calculated energy savings of more than 9 % were confirmed by several different measurements. The revamped furnaces need 30 kWh/t less power to melt the charge materials (Fig. 6).

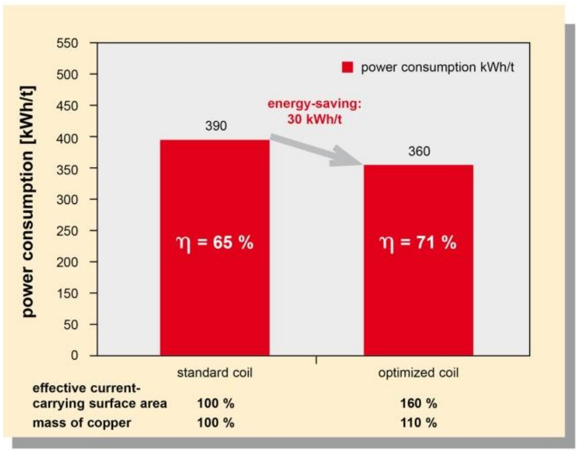

Fig. 6. Results of using the energy-saving coil.

In the meantime, coils of this design have been operating successfully in additional furnace systems built to melt cast iron as well as aluminium and copper grades.

HOLDING – STORING – HOMOGENIZING

Integrating suitable induction furnaces for holding and storing the liquid iron into the melting and pouring operation chain may, in appropriate cases, be helpful from a quality assurance and efficiency improvement perspective.

Depending on the type of primary melting source – i.e., cupola or induction furnace – the basic task of the storage and holding furnace differs. While in a cupola operation the aim is to homogenize the melt composition and temperature distribution apart from storing the liquid iron, the focus in an electric melting shop is usually only on melt storage. Still, in individual cases, the melt storage furnace in an electric melting shop may also be used for necessary alloying operations, e.g., to produce diverse material grades from one base iron. Likewise, it may on occasion serve as a back-up melting furnace if temporary variations in liquid iron demand call for a higher melt output.

The classic melt storage unit is doubtless the channel-type induction furnace, which has proven its merits in day-to-day foundry practice in both cupola and electric melting operations. Coreless induction furnaces are increasingly finding their way into this application in electric melting shops, especially where more flexibility is required.

Equipment

In the production of high-quality castings, it may be advantageous to use a storage furnace downstream of the cupola melting system in order to ensure a homogeneous iron quality and to be able to run the cupola under optimum conditions as continuously as possible, as the cupola is a furnace basically characterized by a high level of control inertia.[8] Depending on the cupola operating regime in conjunction with the charge materials situation, cupola iron will frequently exhibit major variations in melt composition and temperature, as shown in Table 1.

The use of an appropriately sized channel-type induction furnace to compensate for these fluctuations thus becomes indispensable if elevated reject rates and casting quality impairments are to be avoided. Needless to say, the storage furnace also serves as a buffer to cover fluctuating melt demand in the moulding shop. To this end, it handles the discontinuous tapping of molten iron from a continuous supply (cupola).

Pressurized pouring furnaces may be helpful in meeting close melt composition and temperature tolerances. However, because their capacity is too small, they do not qualify as a substitute for a central melt storage furnace. A pouring furnace is commonly sized so that its useful capacity covers roughly a half hour's molten iron demand. It thus provides an additional, albeit not very large, buffer between the melting and moulding operations.

Where one grade of base iron from the cupola is then processed into various cast iron grades, the requisite fine-alloying work can be carried out in an induction furnace.

In specific situations, more particularly where very large parts must be cast in batch mode, even melting shops relying solely on induction furnaces reserve an additional – coreless or channel type – induction furnace as a melt storage unit. This way, highly flexible melting operations can be realized. Moreover, in some cases where tandem-type multi-frequency coreless induction furnaces are newly installed, each furnace's capacity and power rating is selected such as to ensure that the tandem system will provide a highly efficient storage and melting capability as well. Thus, such systems meet both requirements and eliminate the need for a separate storage furnace.

In summary it can be said that, for reasons of process technology, any storage and holding furnaces employed in a cupola melting shop will nearly always be of the channel induction type. In electric melting operations, on the other hand, there exists a real alternative between a channel type or coreless induction furnace for this task. Table 4 shows a comparison of both furnace types.

Table 4. Holding, storing and homogenizing in channel vs. coreless furnaces

Holding, Storing and Homogenizing
In a channel vs. coreless furnace

Furnace type	Channel furnace	Coreless furnace
Specific holding power consumption (related to 40 t total capacity)	6.75 kW/t	10.0 kW/t
Superheating efficiency (from 1,300 auf 1,400 °C)	90 %	80 %
Alloying work	within limits	very good
Slag-free pouring	very good	good
Slag introduction/ Slag formation	very low	low
Continuous mode of operation	very suitable	unfavourable
Batch-type operation and alloy changes	unfavourable	very suitable
Extra melting capacity	within limits	very suitable
Flexibility	limited	very high
Refractory lining	complicated	easy
Temperature homogeneity	good	very good
Simultaneous filling and pouring	very good	within limits
Homogenizing and analysis adjustment	good	very good
Mg treated iron	good	impossible

Undeniably, a channel induction furnace is the appropriate melt storage vessel for a cupola melting shop working in multiple shifts, although the furnace must be kept heated continuously over non-working weekends as well. This disadvantage is more than compensated by the process benefits of this furnace design, e.g., uniform continuous filling and discontinuous tapping plus high efficiency in holding and superheating the melt throughout the production cycle.

For all that, the ratio between production time and pure holding time (without production) must not get too unfavourable since the cost efficiency of the channel furnace would otherwise suffer. According to a British study, holding operation in production accounts for a mere 35 % of the channel furnace's total energy consumption if the plant operates only in two shifts with no production on weekend.[9] Consequently, in this case by far the greatest part of the unit's energy demand is expended on holding the target temperature during non-production times.

As mentioned above, a real choice between a coreless or channel-type holding and storage furnace exists only in an electric melting environment. Here, the size and power density of a new medium-frequency coreless induction furnace can be selected so as to obtain a single plant with flexible melting and holding characteristics. Tandem systems in particular provide a simultaneous melting and storage capability by relying on two furnace vessels served by one joint electric powerpack. Today's frequency converters can split the total electric power input steplessly between two or more furnaces. Apart from the proven tandem installations, solutions with three furnace vessels on one powerpack have likewise been realized. A plant of this type can store fairly large iron volumes; it also supports the simultaneous production of different alloys and delivers high melt rates. Further advantages lie in the fairly low investment and floorspace demand of such solutions.

Energy consumption

For an electric melting operation in which both furnace types would be useful, we examined the question as to which is the most appropriate furnace for the melt holding and superheating function from an energy management viewpoint. More specifically, we took a look at the energy consumption of one coreless and one channel-type furnace for holding and superheating (by 50 K).

To this end, the specific energy consumption of a 40-tonne coreless induction furnace and for a channel-type furnace of the same capacity was analyzed at a throughput of 10 tonnes/h in one-, two- and three-shift operation. It was assumed that in one- and two-shift mode the coreless furnace would be re-started (i.e., heated up anew) every day. This is the least favourable option for a two-shift scenario. In the three-shift case, a restart was assumed to occur at the beginning of each week. A total production time of 47 weeks was considered. The channel-type furnace was assumed to remain in holding operation for 52 weeks. The results are summarized in Fig. 7.

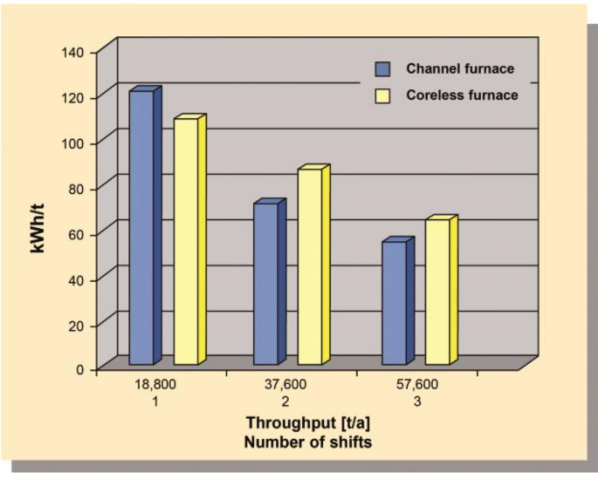

Fig. 7: Energy consumption of channel and coreless furnaces

In terms of energy consumption per tonne of throughput, the channel-type furnace returns a higher figure than the coreless unit only in the one-shift scenario. In two- and three-shift operation, the channel furnace shows energy efficiency advantages throughout. A comparison of these calculations for the two-shift channel furnace case against the results of the British study mentioned above[9] shows a good match (our calculation: 66.2 kWh/t, figure according to the British study: 69.7 kWh/tonne).

It should be noted, however, that the specific holding power consumption diminishes with increasing furnace size. While the consumption of a 40-tonne channel furnace amounts to 6.75 kW/t, the corresponding figure for a 90-tonne furnace is as low as 4.00 kW/t. The average energy consumption of 11.4 kWh/t for holding and superheating (20 K)[10] molten iron in a 105-tonne channel furnace certainly constitutes a very good figure and confirms the energy efficiency gains achievable with a larger furnace unit running at high throughput in multiple shifts.

On the other hand, the same applies in principle to the coreless furnace as regards its specific energy consumption in holding and heating modes, but above all in melting operation; all these figures decrease as the furnace gets bigger. Nonetheless, a certain minimum power rating is required for a given furnace size as the furnace's efficiency in melting operation would otherwise drop too severely. This correlation shall be explained in more detail below. As the overall efficiency of a melting plant is highly dependent on the holding-power-to-rated-power ratio, efficiency decreases with rated power on a furnace of a given size. The power consumption rises and melt output decreases accordingly. This means that there exists a certain practical limit for the use of a coreless furnace as a combined storage and backup melting unit. To keep the melting power consumption within acceptable limits while ensuring an adequate melting rate, the furnace's power rating should be at least 4 to 6 times the holding power. From this perspective, a coreless induction furnace holding, e.g., 12 tonnes should have a power rating of at least 1,000 to 1,500 kW (Fig. 8). Based on practical experience, coreless furnace systems with capacities of 12 to 60 tonnes and 1,500 to 8,000 kW of rated power are used for such tasks. Needless to say, different furnace sizes and power densities are also conceivable on an individual project basis.

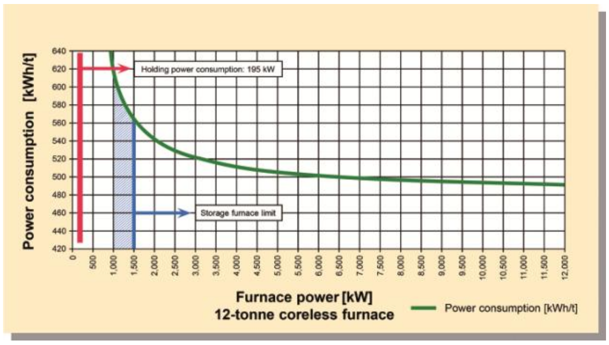

Fig. 8. Limits to the use of a 12-tonne coreless furnace as a storage unit.

Summing up, when it comes to the choice of furnace type and furnace size, production and process technology requirements should be considered first and foremost, aside from energy consumption aspects.

TRANSPORT AND DISTRIBUTION

Equipment

For the task of transferring the molten iron from the (primary) melting furnace to the next process step, there are basically just two options. One consists in the use of a transfer launder, the other is the transport ladle.

Especially with continuous-type melting systems like the cupola, launder systems are employed for moving the molten iron to the holding furnace.

For the coreless induction furnace, which operates on the batch principle, it is common practice to tap the melt into a ladle for further handling. Launder systems are also used in exceptional cases when a pouring furnace is coupled directly to the melting furnace.
In the production of spheroidal graphite iron, the magnesium treatment is often performed in the ladle using a master alloy. In these cases the ladle serves as a melt treatment and transport vessel at the same time. However, a particularly slim ladle is preferred in this case in order to maximize the magnesium yield.

In hand moulding and with mechanized moulding lines it is common practice to transfer the melt to the individual moulds for pouring, as opposed to conveying the moulds to a central pouring station. On indexing high-performance automatic moulding lines, however, there exists one stationary pouring station. The pouring device or pouring furnace is moved only slightly if, e.g., the sprue cup position changes in the moulding box or the mould thickness varies on DISA lines. In continuous conveyor-type moulding systems the pouring device or tundish must travel with the moulds for the duration of the pouring cycle.

Ladles can be handled with the aid of forklift trucks, cranes or monorail systems. Floor-based transport by forklift truck is widespread, while the use of railbound conveyor or car systems has remained very rare. Forklift trucks have the benefit of providing a very high flexibility in terms of timing, destinations and routes. Overhead monorail systems, on the other hand, are fairly stationary and their use therefore requires precise planning and organization. The use of parking or buffer sections, while supported by these systems, helps only with short stops and interruptions of the iron offtake at the pouring station. High technical safety standards, moreover, have increasingly limited the use of overhead conveyors.

Energy consumption

The temperature losses incurred in the distribution and transport of molten metal to the casting station are not to be neglected. Experience shows that every melt transfer operation is associated with a temperature loss. The magnitude of this loss increases with the pouring height and with decreasing pouring rates. For the step of pouring metal from an induction furnace into the transport ladle, we can thus derive the following rule: The ladle should be offered up as closely as possible to the furnace spout, and the pouring cycle should be kept as short as possible to avoid any excessive temperature loss. In practice, a temperature loss of up to 20 – 40 K can be expected during tapping of a medium-sized coreless induction furnace. In OTTO JUNKER's own foundry, a temperature loss of 20 – 25 K was measured during tapping of a 2-tonne furnace into a preheated bottom-pouring ladle.[11]

Additional energy is lost during transport of the liquid metal. If launder systems are used, which is common practice in cupola melting operation, the temperature losses are determined by the launder shape and design. Launders should be kept as slim as possible and covered with a lid to reduce radiation losses. The right geometry of the launder and a cover may reduce temperature losses from 50 K down to 4 K, related to a launder length of 6 m and a throughput rate of 10 t/h (Fig. 9).[9]

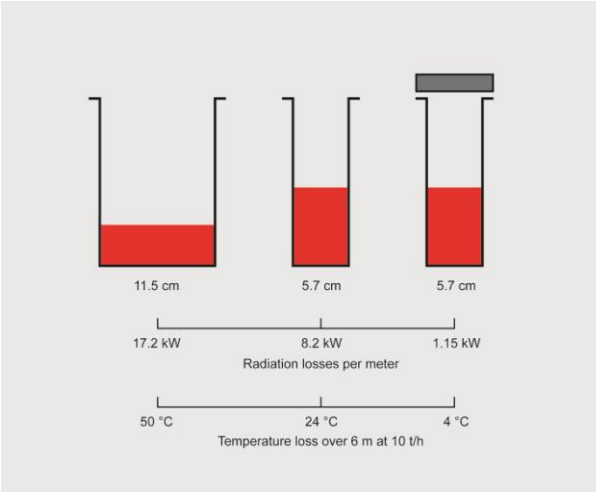

Fig. 9. Effect of launder geometry on temperature loss.

Also the temperature loss in the ladle during liquid metal transport is by no means insignificant. In a crucible-type pouring ladle with a capacity of 2 tonne (without lid), this temperature drop can be put at approx. 6.5 K/minute. It follows that an unnecessary 10-minute holding cycle is associated with a thermal loss of 65 K. The corresponding amount of superheating in the melting furnace would require an additional 25 kWh/tonne.

The slimmer the open crucible-shaped ladle the lower will be the losses, since the heat-radiating melt surface will be smaller for an identical ladle volume. A marked decrease in temperature loss can also be observed with increasing capacity. With a 4-tonne crucible-type ladle without lid, for instance, the loss is as low as 3.5 K/min (Fig. 10). A simple technique can go a long way towards cutting temperature losses: The use of a drum-type ladle may bring down thermal loss to a mere 1.5 K/min (related to a 4-tonne ladle). The use of a ladle lid also brings down the thermal loss significantly.

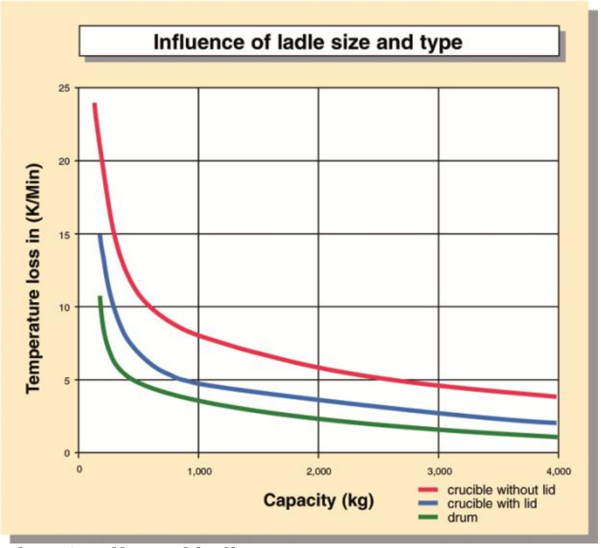

Fig. 10. Effect of ladle geometry on temperature loss.

Naturally, the temperature loss in the ladle may also be minimized by improved thermal insulation, whether by adopting a thicker lining or by using a less heat-conducting refractory material. The use of insulating ladle linings allows more uniform pouring temperatures to be obtained. In some cases even the tapping temperature could be reduced.[12] Jacketed ladles are another possibility of saving energy and reducing the temperature losses.[13] It should also be noted that it will definitely pay off to preheat the ladle and to let the lining dry properly.

For longer transport distances, a larger ladle should be preferred because of the lower specific losses involved. Its contents can then be transferred into smaller ladles at the pouring station to minimize the aggregate loss while keeping the pouring temperature at the required level.

POURING AND DOSING

Equipment

For pouring and dosing molten cast iron in moulding lines, there basically exist three equipment alternatives: the traditional manually operated pouring ladle (crucible or drum type), unheated pouring vessels (emptying either through a bottom stopper or via a pouring spout when tilted), or a pressurized pouring furnace of the channel or coreless inductor type tapped via a stopper mechanism.

The ever more exacting demands on the quality of castings call for ever closer tolerances in pouring parameters and dosing accuracy. Thus, for instance, pouring temperature tolerances of 15 K and dosing accuracies of under 1 % by weight are by no means rare in the production of high-quality automotive castings today. Moreover, the high-performance moulding machines now typically employed in volume manufacturing depend on an accurately metered filling of a mould every 10 to 15 seconds. In this process, the melt flow must be accurately adapted to the mould's intake capacity while reproducing the optimized pouring curve with a high degree of repeatability. Both the pressurized pouring furnace and unheated pouring devices support an automated pouring process. For such automation, two basic methods are available. One is to follow a previously stored, mould-specific pouring curve created by a teach-in process. The other is to control the pouring rate by measuring the level of liquid iron in the sprue cup of the mould box using a camera or laser distance measuring system.

In manual pouring from a ladle, on the other hand, the pouring process relies on the operator's individual trade skills and daily form. Conversely, on a high-performance moulding line it is not a forward-looking solution to fill the mould boxes by manual pouring at a fast pace. But where small production runs and individual parts are hand moulded or made on a mechanized moulding machine, it still makes sense to pour metal manually from a ladle. In individual cases this may involve basic mechanization solutions for moving and docking the ladle into the pouring position. However, an accurate control of the pouring temperature is absolutely indispensable when working with pouring ladles. The number of pours from one ladle depends not just on the pouring weight but also on the acceptable pouring temperature tolerance. No matter how well the pouring ladle is insulated or designed, the temperature drop can be minimized but not avoided.

One method of achieving near-constant pouring temperatures even with longer holding times in the pouring ladle consists in the use of an inductive ladle heating system.[14,15] However, for a variety of reasons, such systems have not become widespread in industry. With the development of the INDULADLE system (Fig. 11), a solution has become available which is of proven effectiveness and delivers energy efficiencies of around 70 % in the holding process.

Fig. 11. The induction heated INDULADLE.

Modern unheated pouring systems can meet demands on pouring automation but cannot ensure the necessary temperature uniformity and extended storage of magnesium-treated melts. The pressurized pouring furnace, which is typically heated by a channel-type inductor, can compensate for heat loss to maintain a constant melt temperature in addition to its superheating capability. The melt can thus be superheated to the requisite pouring temperature when the incoming metal is not hot enough. Depending on the installed power of the electrical powerpack, a temperature rise by 50 - 100 K is achievable within one hour.

The advantages of unheated pouring devices over a pouring furnace lie in their ability to support iron changes (i.e., a switch to another material grade) quickly and easily, in addition to their lower investment and operating costs (lining, maintenance, etc.) and the fact that they can be started up rapidly and conveniently. Both vessel types create an additional buffer between the melting and moulding operation, although they differ in capacity. While pouring furnace capacities are commonly rated to be roughly equal to between a half hour's and one hour's iron demand, the time factor must be additionally taken into account with an unheated pouring system. Because of the temperature drop, the stored quantity of iron needs to be poured and refilled after no more than 15 – 20 minutes.

An induction-type pouring furnace, on the other hand, can hold molten metal for a virtually unlimited time in case the melt offtake is disrupted. Needless to say, this holding capability is achieved at the cost of a given energy input.

The use of a pressurized pouring furnace specifically permits the following:

- precise movement to various pouring positions;
- accurate reproduction of a predefined pouring curve;
- exact dosing of the necessary iron quantity;
- holding and superheating;
- maintaining a uniform pouring temperature;
- analysis adjustment;
- slag-free pouring;
  and
- an extended storage of magnesium-treated melts.

Energy consumption

Aside from the technological advantages, the use of a pouring furnace offers clear energy efficiency benefits.

In addition to the direct energy savings achieved via the lower heat loss of the pouring furnace, indirect gains are obtained through

- lower temperature loss due to fewer metal transfer operations;
- reduced amounts of iron residue and spillage;
- minimized returns (smaller sprue cups);
- shorter process management downtimes
  and
- better and more continuous utilization of the melting capacity.

Together, these factors translate into reduced manufacturing costs and enhanced capacity utilization.

The static temperature loss (heating system deactivated) of liquid iron in a medium-sized (4-tonne) pouring furnace is very low at 0.5 K per minute, so the holding energy input is low as well. Compared to the temperature loss in a standard lidless (crucible-type) ladle which averages 4 K per minute, the static temperature loss over a 20-minute holding period thus drops from 80 K to 10 K. The resulting 70 K reduction in temperature loss translates into energy gains of over 30 kWh/tonne, refer to Fig 10. This tallies with the statement that the use of a pouring furnace allows the tapping temperature from the melting or holding furnace to be reduced by 30 - 60 K.[16] It remains to be mentioned that the specific holding power consumption drops markedly with increasing furnace size. A larger pouring furnace would thus yield a further energy efficiency gain. However, this advantage cannot be utilized unreservedly as the pouring furnace size is determined first and foremost on the basis of production technology needs.

If a coreless inductor is used instead of a channel-type inductor for heating the pouring furnace, a 15 % higher energy consumption should be anticipated in both holding and superheating mode.[16] For this and other reasons, this design variant has not become as widespread on induction pouring furnaces as most observers had expected at the outset of this development.

If the pouring furnace is compared with an unheated pouring device in terms of total energy consumption (and hence, energy efficiency), the respective benefits and drawbacks need to be carefully weighed. An advantage of the unheated pouring device is that it requires no heating on weekends and non-working shifts. On the other hand, it too will consume energy for re-heating after every such non-working period.

On the other hand, in day-to-day production use, the temperature loss of an unheated pouring system is much higher than that of a pouring furnace. While the pouring furnace loses approx. 0.5 K per minute, the figure for an unheated pouring system is much higher. According to the manufacturer's own measurements, the temperature loss on an OTTO JUNKER unheated pouring system exceeds 2.5 K/min; other manufacturers of unheated pouring systems quote values between 1 – 1.5 K/min[17] and 5 – 10 K/min[18], depending on design and execution. For our further discussion a mean value of 2.5 K/min has been used. This translates into a temperature loss of 50 K after a 20-minute holding cycle (without heating – static heat loss).

Clearly, an unheated pouring system can only deliver an energy advantage over a pouring furnace when it is used in single-shift operation, or where iron changes or extended interruptions are frequent. A calculation of the mean energy demand in kWh/t, carried out for a throughput of 4 tonnes/h and various shift schedules, supports this qualitative statement with numerical evidence (Fig. 12). With 2-shift working, an induction-type pouring furnace will already yield significant energy savings compared to an unheated pouring system. Although the specific energy consumption drops with increasing throughput, the shift schedule employed remains the determining factor; thus, the basic differences in energy demand patterns of these two pouring systems remain unresolved.

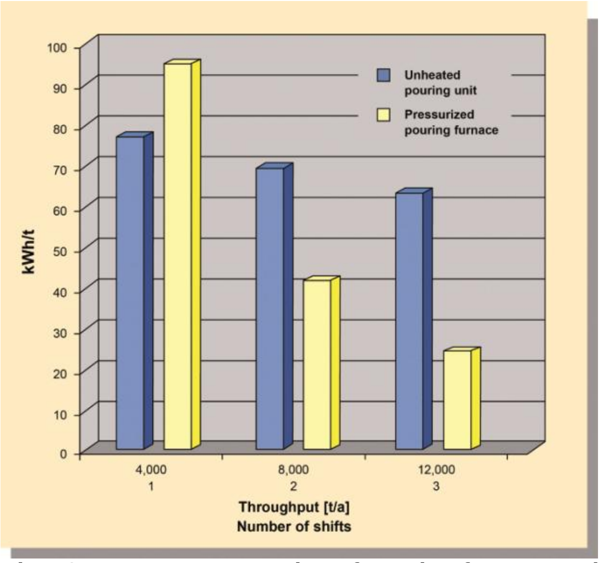

Fig. 12. Energy consumption of pouring furnace and unheated pouring device.

CONCLUSION

The use of induction furnaces for melting, holding, storing and pouring contributes in a major way to improved quality assurance and cost efficiency in the production of high-grade iron castings. The good energy efficiency of these systems can be further improved through a proper equipment selection and adoption of favourable management and operating regimes.

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