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Batch cooling – optimized cooling for used sand

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In January 2001 the V. Birn foundry in Denmark commissioned a batch cooler with a maximum capacity of 8 t. It is capable of cooling a 6 t charge from 120 to 41 °C within 120 s. This capacity is achieved with a classical cooling process in which, as with many other used sand coolers, ambient air is the cooling medium.

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Original situation

Two years ago the foundry initiated a new project for used sand cooling because, through the changing of the sixth and seventh moulding lines (Disamatic), it would no longer be possible to handle the increased amount of sand with the existing fluidized bed cooler. The project allowed for a throughput of 400 t/h and cooling of the sand from 170 to 40 °C. Normal daily capacity amounts to around 300 to 350 t/h with a maximum sand temperature of 120 °C.

Fundamentals of sand cooling

In order to determine the most suitable cooler it is sensible to compile an energy balance, which can provide information on the required water and air volumes for cooling.

In principle, the initial physical step is described by the energy balance. The heat energy amounts to

$$Q = M \times \Delta T \times c$$

Where

M = sand mass
ΔT = temperature difference by which the sand is cooled
c = specific heat capacity: for sand 0.84 kJ/(kg·K)

The corresponding figures for the Birn foundry are as follows.

With a sand mass of 400000 kg, cooling should amount to 130 K, corresponding with a heat energy of 43.6 GJ which has to be removed from the sand by the vaporization of water.

2 613 kJ are required for the evaporation or vaporization of 1 l water with an initial temperature of 15 °C. For 43.6 GJ this results in a water requirement of 16 716 l. In general the water requirement W is represented as

$$W = Q/2613 \text{ l}$$

With this considerable water requirement it makes no difference which cooler is used with which process. The heating of the water alone is less important. The meaningful factor is the vaporization, i.e. transformation of the water from the liquid to the gaseous state.

The significant factor is the answer to the question as to what volume of air is required in order to remove this water volume.

Contrary to the energy balance formula, the water absorption capacity of the air is not linear. As the air temperature increases so is it able to absorb a greater percentage of water **(Figure 1).** Some figures from this curve can better illustrate this characteristic. For 1 m^3 air the maximum water absorption capacity (100% relative humidity) at the following air temperatures amounts to:

- 20 °C: 17.30 g/m^3
- 40 °C: 51.15 g/m^3
- 60 °C: 130.20 g/m^3

The aim is for the air to absorb as much water as possible so that as little as possible has to be passed through the sand. This polygon of technical requirements very quickly gives rise to new prerequisites and, in some cases, also serious problems. For example, if a large amount of air is blown through, this necessitates larger blowers for the incoming

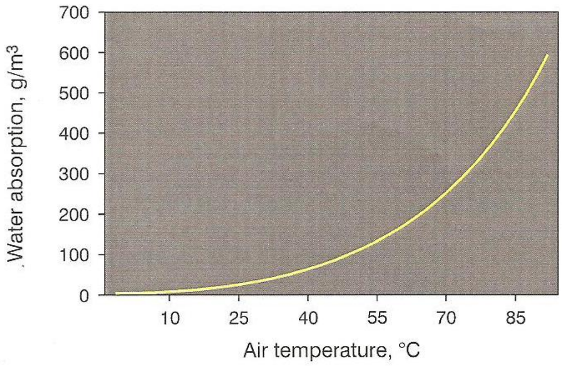

Figure 1. Water absorption capacity of the air in relationship to temperature

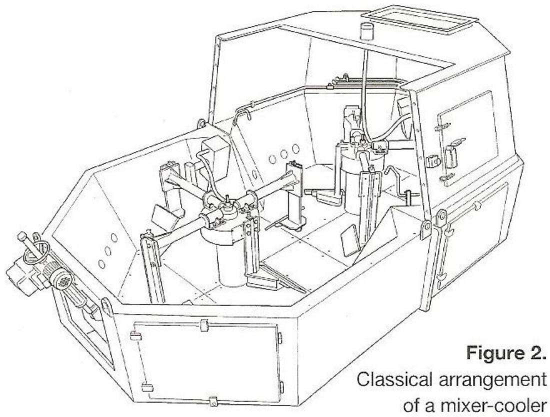

Figure 2. Classical arrangement of a mixer-cooler

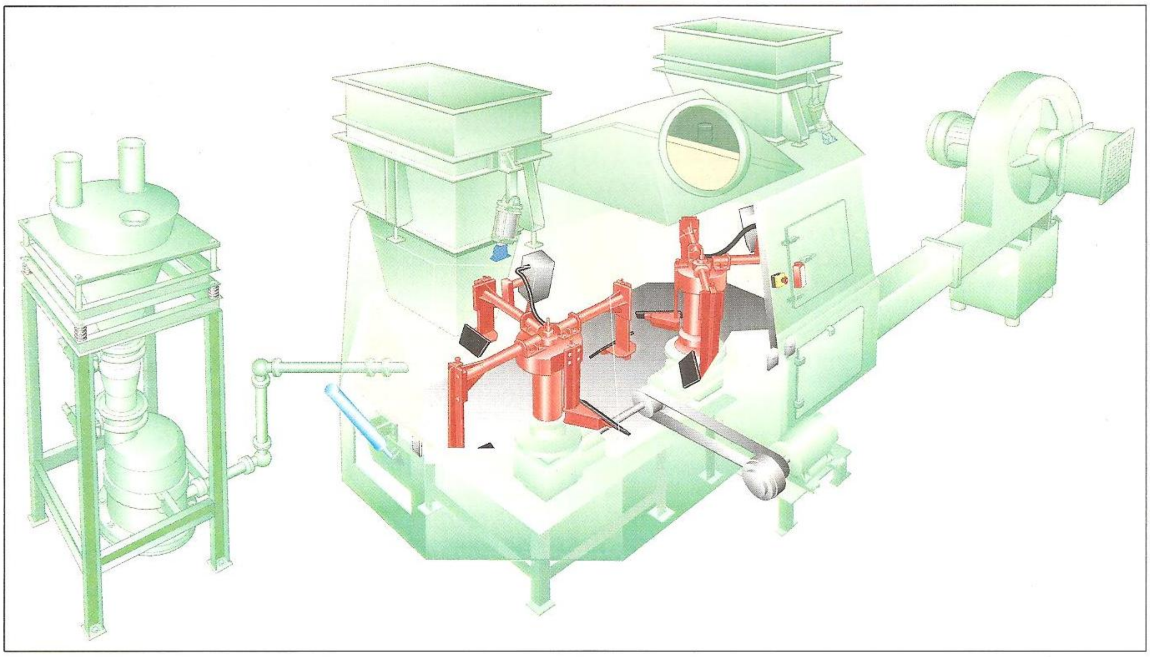

Figure 3. Arrangement of the ADD batch cooler

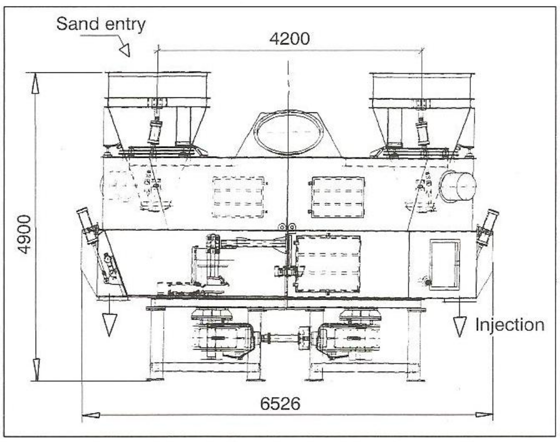

Figure 4. Layout of the batch coolers

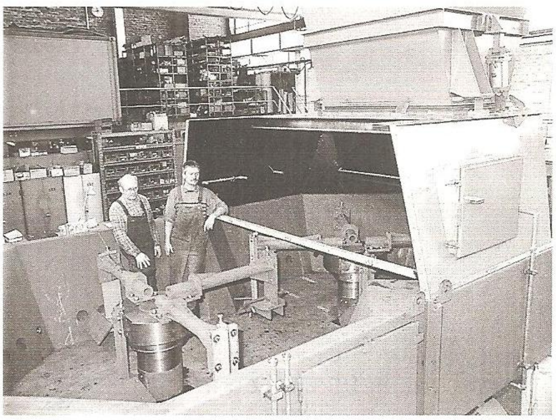

Figure 5. Batch cooler before delivery (M. Lang, Kölner Stadtanzeiger)

and exhaust air. Furthermore, these large air volumes remove many more valuable fine components from the sand, which has a negative effect on the sand quality.

This results in a paradox inasmuch as it is endeavoured to achieve lower sand temperatures but, at the same time, higher air temperatures. The optimal condition would be that where the air temperature is for example 20 K above that of the used sand temperature. In order to have to pass a small amount of air it is necessary to achieve the highest possible exhaust air temperature at which a large amount of cooling water can be absorbed.

Common coolers, such as fluidized bed units or also mixer-coolers that operate continuously, as a rule achieve an exhaust air temperature of around 40 °C, which is mostly below the sand exit temperature. With a water volume of 16716 l, that has to be vaporized, and an exhaust temperature of 40 °C, on the assumption of saturation a cooling air volume of 326803 m^3/h is required. This high air volume necessitates a large plant. Even the daily operation at 300 t/h and an 80 K cooling would necessitate the vaporization of 7715 l/h of water, corresponding with an air volume of 150830 m^3.

The batch cooler

The construction of the batch cooler is based on that of the mixer-cooler. The figure eight shape with parallel agitators and air inlet on the side has remained unchanged. A new feature is the weighing scales for always dosing the same amounts of sand in batch operation. A binder injection system can be integrated as an optional extra **(Figures 2** to **5).**

In order to deal with these large amounts of sand two 8 t-capacity batch coolers were constructed, each with two 4 t weighing facilities in the cooler hoods. The design specification included an exhaust air volume of 40000 m^3 per cooler and an inlet volume of 30000 m^3. Two 2″ water mains were provided in order to be able to dose around 500 l for the maximum batch capacity of 8 t with a discharge moisture of 2%. Two cyclones per cooler were provided for extracting the fines carried out in the exhaust air.

The position of the plant is unusual because of restrictions on height. Consequently, it is installed in a 55 m long shaft that in places is 8 m deep and 10 m wide. A moulding plant is above it at ground level. Only the cyclones protrude above **(Figures 6** and **7).** All the installation work was carried out in parallel with production. The plant was fully incorporated in the existing sand circulation system at the beginning of this year.

Control and measuring techniques

The control functions are a combination of mixing and continuous cooling, the parallel processes being sequentially carried out in the cooler. The final expansion stage – cooling with binder dosing – incorporates the following phases:

1. Dosing of used sand and binder into the relevant weighing devices;
2. Simultaneous charging of the cooler with used sand and water;
3. Switching on and off of the air feed;
4. Addition of binder by injection;
5. Emptying of the cooler.

The great unknown in the cooling process is the air. It is not clearly predictable as to what temperatures occur in the exhaust air and what cooling action is finally achieved in the sand. There is no corresponding formula because the construction of the cooler is the decisive factor. The control sequence provides for a fixed cooling time and not a variable, which is orientated towards achievement of a set temperature. In so doing, allowance is made for the carry-out of dust because with a different cycle time different amounts of dust and/or fines are carried out and the sand system becomes more and more unbalanced. Thus, a cooler sand remains in the cooler for exactly the same amount of time as one with a higher temperature.

The water addition is made up of two parts. These are determined on the one hand from the difference between the set and the actual moisture because the used sand is not only cooled but must also be provided with a basic moisture and, on the other hand, from the cooling water requirement that is determined from the measured sand temperature during dosing of the charge. During the cooling process the vaporization process is completed through measurement of the exhaust air temperature.

Experience

The coolers installed in the V. Birn foundry were the first of their type and were subjected to extreme requirements with regard to throughput and temperature profile. After six months operation it was possible to evaluate their performance.

Two questions were of interest with regard to the construction of the cooler:

1. Where was it possible to find an optimal mode of operation under consideration of
   - the entry temperature and the required exit temperature,
   - the still acceptable dust carry-out (sand system and dumping costs) and
   - the required sand throughput.
2. Was it already possible to deterministically assess the approximate discharge values during design of the cooler. Up to now only a vague estimate was possible, this being based on intuitive experience.

Air entry temperature

A series of tests was carried out to establish the behaviour of this cooler. In so doing it was possible to refer back to data from two extremely different climatic conditions. The first data was recorded in winter under air entry temperatures from 1 to 5 °C, the second in June with 20 to 25 °C. A comparison between these two series of measurements immediately revealed that higher entry temperatures also result in higher exit temperatures. 15 K difference in the entry air results in a 3 to 5 K increase in the sand temperature **(Figure 8a).**

In actual fact, this effect enables calculation of the energy balance and the different volume of the vaporized water in the entry air. With a 2 min cooling time, at 1 °C only 3 l of water is introduced but at 20 °C a little less than 11 l. This 8 l difference then results in a reduction of around 4 K in the cooling action.

Cooling time

It is easy to vary the cooling time in a batch cooling process. In so doing it should be determined as to what influence the cooling condition has on the cooling time. In par-

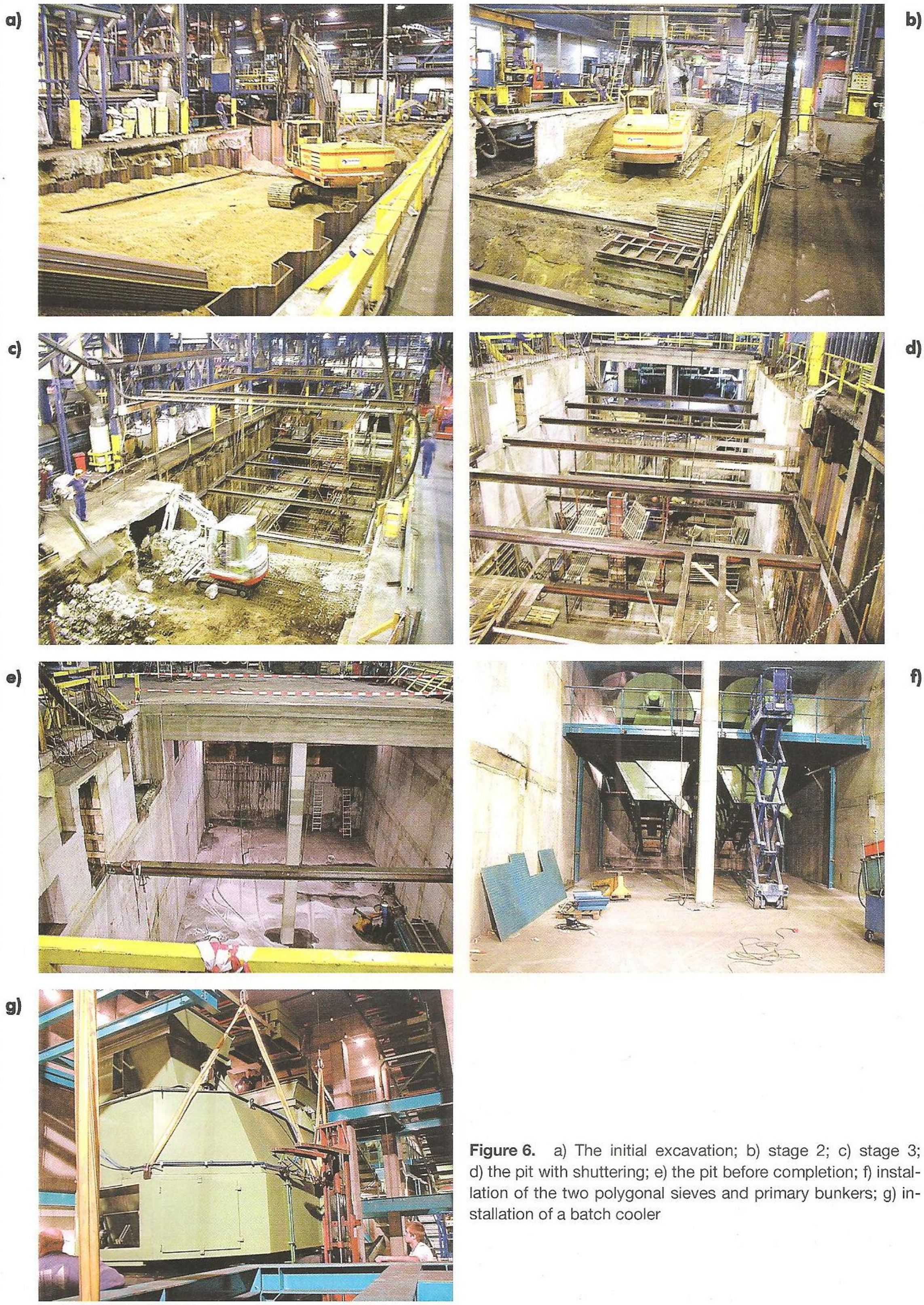

Figure 6. a) The initial excavation; b) stage 2; c) stage 3; d) the pit with shuttering; e) the pit before completion; f) installation of the two polygonal sieves and primary bunkers; g) installation of a batch cooler

Figure 7. View of the internal parts of a batch cooler

ticular it is necessary to discover when the most intensive phase of the cooling occurs.

Figure 8a also shows the cooling action in relationship to time. It is possible to see an approximate 2 K reduction in the discharge temperature when extending the cooling time by 10 s. The decisive cooling action occurs in the first seconds when the used sand comes into contact with water in the cooler. After 30 s a 95 °C charge is already reduced to 60 °C. After this the cooling effect is considerably less, the remaining 80 s only bringing a reduction of around 12 to 15 K. However, the cooling time cannot be further shortened because the addition of water alone takes 30 s. **Figure 8b** illustrates this effect – also for different batch sizes and entry temperatures.

Batch size

A further series of tests was carried out in order to determine how the cooling capacity of the 8 t batch cooler varies with different batch sizes. Between 5 t and 8 t the differences were only small. With the same entry temperature and the same cooling time the discharge temperature increased by around 4 K, this difference also being the same with variation of the cooling time. **Figure 8b** shows the discharge temperatures for five batch sizes with two cooling times. This effect can also be seen in **Figure 8c.**

Air flow volume

It was investigated as to what extent the air volume can be reduced with resultant worsening of the cooling capacity. Under operational conditions it was not possible to vary the exit and entry air in finely differentiated stages in order to reconstruct a reliable curve between two basic points.

With 25% less air volume the exit temperature increased by around 4 to 5 K. A 25% increase in the cooling time resulted in approximately the same temperatures.

Blower capacity and percentages of fines

The very high blower capacity for generation of this considerable volume of air has an effect on the extraction of fines, which considerably changes the condition of the sand. The use of cyclones enables the dust to be fed back into the sand but, in spite of this, the sand changes because these fines originate from the grain envelopes, the function of which is the holding together of the conglomerate. A straight return does not automatically lead to their return to the grain envelope, so that it is sensible to consider reduction of the extraction of the amount of fines. The previous investigation of the reduction of the air volume should have this effect.

For this purpose the carry-out at the cyclone outlet was captured and weighed, 3 values being determined which are proportional to each other in volume and time. Starting with a cooling time of 110 s for 7 t sand the fines amounted to 190 kg but halving the cooling reduced this to 104 kg. A reduced air volume and 140 s cooling time resulted in the extraction of 200 kg, i.e. the fines extraction is proportional to

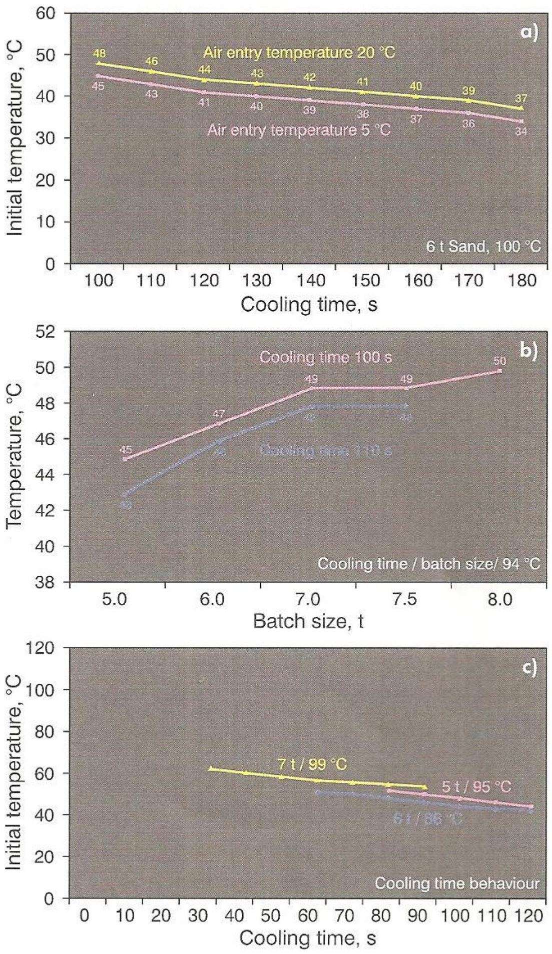

Figure 8. Relationship between cooling time and a) air temperature; b) batch size; c) cooling effect

the time. If the air volume is reduced but the time extended the extraction is similar, i.e. there is no positive effect with reference to the reduction of the dust carry-out.

Evaluation

The batch cooler is more efficient than the continuous cooler. The achievable temperatures are at least 5 K lower and the air requirement is less. Additionally, the two agitators achieve better homogenization.

The cooling action is more effective than that in the continuous cooler. The dwell times are around 2 min, as against 3 min. This allows higher throughputs with less extraction of dust from the sand. Tests have resulted in the fact that the exhaust air extracts 1.5% of the charge per minute in the form of dust.

The cooling capacity is more effective for the following reasons:

- The hot sand immediately comes into contact with water and air; a large amount of water is immediately vaporized, which leads to considerably fast cooling. With the batch cooler the decisive cooling effect occurs at the beginning of the cycle because water and air simultaneously come together with the hot sand.
- The exhaust air temperature is higher and a larger volume of cooling water is carried with it, resulting in more intensive cooling. The action is better because in the continuous cooler already cooled sand mixes with uncooled sand; the total temperature goes down and the exhaust air is thus heated up less. The batch cooler exhaust temperature is approx. 10 K higher at 50 °C.

Outlook

In addition to the better cooling action, with this method it is possible to add the binder in the batch cycle as soon as the air feed is switched off. It is thus possible to parry a typical effect in jobbing foundries, namely, strong fluctuation in the sand properties through frequently changing programmes. Coupled with a flask tracking programme a moulding material balance enables automatic determination of its own recipe for each charge.

Calculation example

Technical data:

	Throughput	Cooling from	Cooling to
Maximum requirement	400 t/h	170 °C	40 °C
Daily requirement 1	350 t/h	120 °C	40 °C
Daily requirement 2	300 t/h	120 °C	40 °C

Heat extraction Q

$Q = M \times c \times \Delta T$

M = Sand mass, kg
c = Specific heat capacity for sand: 0.84 kJ/(kg·K)
ΔT = Temperature difference, K

Q_{max} = 400 000 kg × 0.84 kJ/(kg·K) × 130 K = 43 680 000 kJ
$Q_{daily\,1}$ = 350 000 kg × 0.84 kJ/(kg·K) × 80 K = 23 520 000 kJ
$Q_{daily\,2}$ = 300 000 kg × 0.84 kJ/(kg·K) × 80 K = 20 160 000 kJ

Cooling water requirement

Specific heat capacity of water: 4.2 kJ/(kg·K)
Evaporative heat of water: 2256 kJ/kg

1 l of cooling water at 15 °C requires the following energy for vaporization

$Q_w = Q_{(15-100\,°C)} + Q_{vapor}$ = 357 kJ/l + 2256 kJ/l = 2613 kJ/l

Cooling water requirement (thermal energy/vaporization energy):
Maximum requirement = 43 680 000/2613 = 16 716 l
Daily requirement 1 = 23 520 000/2613 = 9 001 l
Daily requirement 2 = 20 160 000/2613 = 7 715 l

Exhaust air volume requirement

Three different exhaust temperatures, namely 40 °C, 45 °C and 50 °C. The water absorption capacities (absolute air humidity) vary. The exhaust air volume is calculated from the cooling water requirement, divided by the absolute humidity. Results are shown in **Table A1.** The considerably increased air requirement at the low exit temperature of 40 °C is clearly recognizable.

Influence of the air entry temperature

The humidity of the entering air reduces the water absorption capacity of the exhaust air. The associated water volume is low but does indeed reduce the cooling action; this can be confirmed via the energy balance.

Information for the calculation:

Air flow volume for a 120 s batch: 40 000 m^3/h:30
Relative air humidity: 50%.
Absolute air humidity at 1 °C = 0.00521 kg
Absolute air humidity at 20 °C = 0.01730 kg

Water volume per batch (1 °C) = 40 000/30 × 0.00521 × 0.5 = 3.47 l
Water volume per batch (20 °C) = 40 000/30 × 0.01730 × 0.5 = 11.53 l

At 20 °C, the entry air contains 8.06 l more water.
The equations for the energy balance and the cooling water requirement are combined and transformed for the required temperature

$\Delta T = W \times 2613/(M \times c)$

where

W = cooling water volume = 8.06 l
M = Batch weight = 6000 kg
c = Specific heat capacity = 0.84 kJ/(kg·K)
ΔT = 8.06 × 2.613/(6000 × 0.84) = 3.36 K

The measured temperature difference of 3 to 4 K can thus be arrived at by calculation. This effect becomes greater as the batch becomes smaller.

Cooling time effect

Extension of the cooling time results in a linear reduction of the sand temperature. In the simplified assumption that the exhaust air temperature always remains unchanged at 50 °C, 40 000 m^3/h of air results in the passage of 111 m^3 in 10 s. The water volume amounts to 9.33 l (50 °C). The temperature difference with a 7000 kg batch then amounts to

ΔT = 9.33 × 2613/(7000 × 0.84) = 4.1 K

This is somewhat higher than the measured temperature differences.

Table A.1. Required exhaust air volumes for different exhaust air temperatures

	Exhaust air volume, m^3 40 °C	45 °C	50 °C	Cooling water, l
Absolute humidity, g/m^3	51.15	65.40	83.00	
Max. requirement	326 803	255 569	201 397	16 716
Daily requirement 1	175 972	137 630	108 445	9 001
Daily requirement 2	150 830	117 966	92 951	7 715