OTTO JUNKER

Publication

Billet homogenizing – Batch or continuous?

Dr.-Ing. Günter Valder
General Technical Manager – Thermoprocessing Equipment
Otto Junker GmbH, Simmerath

Otto Junker GmbH
Jägerhausstr. 22
52152 Simmerath

Tel.: +49 2473 601 – 0
Fax: +49 2473 601 – 600

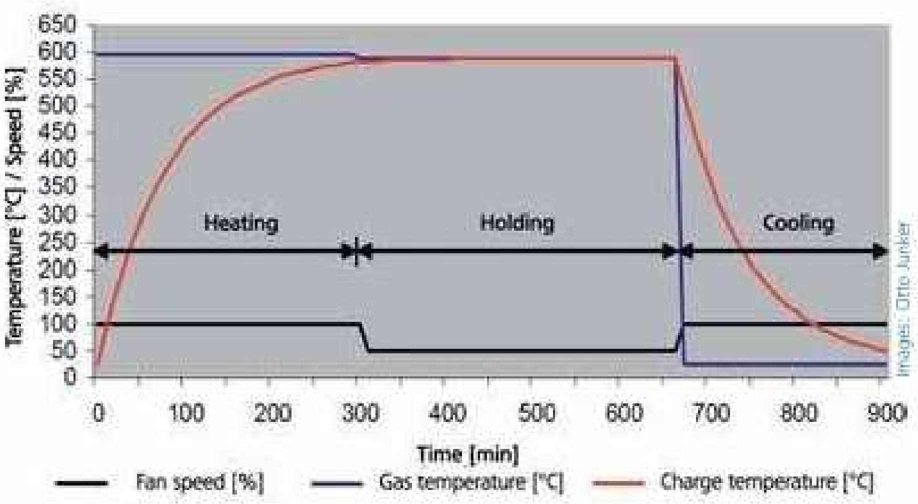
Internet: http://www.otto-junker.de

Billet homogenizing – batch or continuous?

In the production sequence of an aluminium smelter or casthouse the homogenizing furnace is the final heat treatment process before delivery and further processing of the aluminium logs or billets in an extrusion plant. On the market there are two different plant variants established, whose essential distinguishing feature is their mode of operation: continuous, or discontinuous. For both variants Otto Junker offers complete systems. Below, a review of the most important decision criteria for the selection and operation of a billet homogenizing plant is given.

Position and function in the infrastructure of primary and secondary smelters

The processing material for extrusion plants consists basically of cylindrical extrusion bars with diameters of 100 to 600 mm and lengths of 0.5 to 1.8 m, known as ‘billets’, or alternatively ‘logs’ with lengths of 3 to 8 m. These are produced in primary and secondary smelters. In each case homogenizing is the final heat treatment process. This heat treatment step is necessary because during the solidification of the cast log in the mould, an inhomogeneous distribution of the alloying elements is produced across the radial and axial log cross-sections. To produce a uniform distribution of the alloying elements and dissolve the brittle grain boundary precipitates, a homogenizing annealing treatment at 570℃ to 590℃ with a holding time of four to eight hours is carried out. A typical so-termed furnace campaign is shown in **Fig. 1.**



Images: Otto Junker

Fig. 1: Calculated ideal variation of the caloric mean charge temperature and assumed fan rotation speed variation, during the process steps of heating, holding and cooling without excess temperature

The subsequent cooling can take place uncontrolled in room air by natural convection or at a controlled cooling rate by forced convection with air or water. Depending on the alloy, the cooling rate has various effects on the properties of the eventual semi-fabricate. For example, when cooled rapidly AlMgSi alloys form a dispersion of very fine Mg- and Si-rich secondary precipitates, which result in a high force demand during extrusion, a higher extrusion speed, and the development of high strength after final artificial ageing. On the other hand slow cooling results in low force demand during extrusion, but at the same time reduces the extrusion speed and the eventual strength. The Mg- and Si-rich secondary precipitates are fewer but coarser.

The condition in which logs or billets are delivered to the extrusion plant is basically ultrasonically tested, cropped, homogenized, and if the outer surface is likely to have a negative effect on the later extruded semi fabricate, the surface layer can in addition be scalped. For ultrasonic testing a distinction is made between conventional ultrasonic testing and the so-called ‘helial’ testing. Whereas conventional ultrasonic tests are always carried out to exclude cracks within the log, helical testing is applied for safety-relevant components with the aim of excluding additional surface cracks. Otto Junker obtains the test equipment mentioned from an experienced supplier. In the cropping stage the front and rear ends of the cast aluminium log are cut off. For energy-related reasons cropping is carried out before homogenizing so that the front and rear offcuts do not have to be heated unnecessarily. To make use of this effect the flow control in the homogenizing furnace must be designed so as to exclude overheating the edges. Otto Junker has already provided numerous homogenizing lines as complete systems, from taking over the logs from the mould, up to palleting the finished aluminium logs or billets.

Besides the homogenizing furnace, the complete log and billet handling system, including ‘narrow-cut’ saws, is supplied. Homogenizing lines are characterized by a high level of automation, with ‘Level 2’ covered by operator-friendly visualization whereas the archiving and processing of the order and process data can be ensured by connection to the customer’s Production Data Management system (PDM, ‘Level 3’). For secondary smelters the scope of Otto Junker’s deliveries is additionally extended by the necessary melting and holding furnaces. These are designed as single- or multi-chamber hearth furnaces and operate using Thermcon technology, which has proved its worth over many years.

Classification of homogenizing furnaces

Homogenizing furnaces can be classified according to their operating mode (continuous / discontinuous), how they are heated (fuel-fired / electric resistance heated), and according to the flow control method (nozzle-flow / mass-flow) (see Fig. 2).

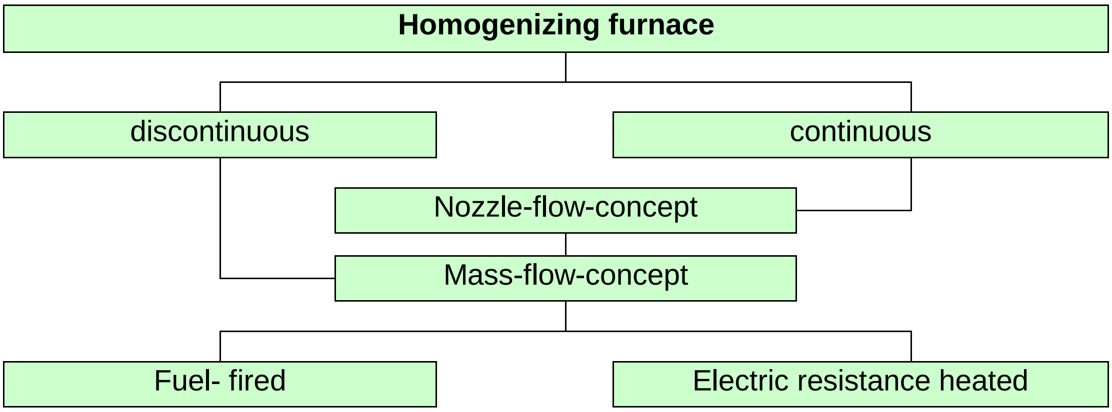


Fig. 2: Classification of homogenizing furnaces

Mode of operation

In continuous homogenizing furnaces the aluminium logs are fed into the unit individually, for example by a walking beam system, at fixed time intervals. The temperature of the aluminium logs changes with time and with the distance covered. In discontinuous (batch-type) homogenizing furnaces batch charges are put together in racks and the temperature of the positionally fixed aluminium logs changes only with time. The temperature differences that occur between aluminium logs on the outside and inside of a batch during heating up can be as much as up to 90 K, so the holding time begins when the innermost logs too have reached the homogenizing temperature. In batch-type homogenizing furnaces designed by Otto Junker this disadvantage is eliminated so far as possible. The heat-up time is shortened at the same time as improving the temperature uniformity by continually changing (‘reversing’) the flow direction of gases flowing through the batch. For this purpose Otto Junker uses special axial fans. These enable the flow direction to be reversed simply by changing the fan rotation direction, and are designed such that in both directions an almost constant volume flow is delivered (see Figs. 3 and 4). At the same time flap-control systems of the type needed when radial fans are used, which can also malfunction under thermal loading, are avoided. Despite these measures, since the logs are heated individually a continuous homogenizing plant still has an advantage in relation to reproducibility and cycle time, because the temperature differences described earlier occur only to a negligible extent and consequently require hardly any equalization. It is also an advantage that no racks have to be heated along with the charge, so that in relation to the net-through-put less energy is needed compared with the batch-type design. That the charge does not have to be separated out on transition from the furnace to the cooling zone can also be an advantage from the metallurgical standpoint: depending on the time required, a metallurgically undesirable pre-cooling due to free convection can take place, which particularly affects the aluminium logs stacked on the outside.

Essential disadvantages of the continuous design are the large area made necessary by the loading of the furnace with a single layer, and less flexibility when format and alloy changes are frequent. Above all when a large diameter range has to be covered, it is found that the multi-layer loading of a batch-type furnace always enables 100% utilization of the homogenizing furnace.

Fig. 3: Discontinuous (batch-type) homogenizing plant with cooling chamber, designed by Otto Junker

Structure and energy transfer

In both designs the basic structure and the heat transfer mechanisms are the same: in an insulated steel housing channels of heat-resistant steel are formed, which enclose the aluminium logs. Hot gas fans and the heating systems are built into these internal housings. Directed towards the aluminium logs, the internal housings have special nozzle systems adapted to the geometry of the charge (see Figs. 4 and 6). The furnace atmosphere is circulated continuously by hot gas fans of radial or axial design, so that the energy flow introduced by the heating devices is first given up to the circulating atmosphere by forced convection. The nozzle system blows onto the charge and, as a result, the energy flow is transferred to the charge to by far the greatest extent by forced convection (85%) and by heat radiation (15%) from the furnace atmosphere. In the discontinuous (batch) design the cooling section is made as a separate chamber, while in a continuous version it is a fixed part of the unit. In each case the structure and consequently also the heat transfer mechanisms correspond to those in the heated portion of the plant. As the cooling medium, as a rule ambient air is drawn in and after flowing through the charge just once, discharged again to the outside. Depending on the alloy, the cooling rates required range between 150 and 550 K/h and these are sufficient for the great majority of requirements; substantially higher cooling rates are an exception and are achieved, above all in continuous homogenizing, by means of intensive air-cooling stretches (700 K/h) or with water cooling systems (> 1,000 K/h).

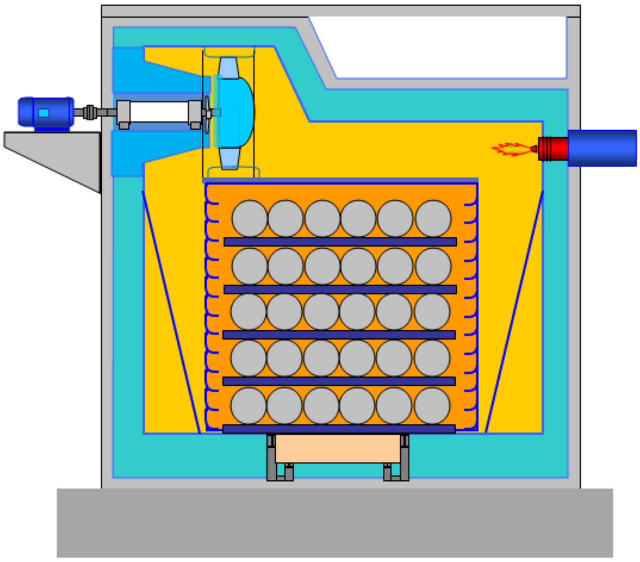


Fig. 4: Cross-section of a directly fuel-fired discontinuous homogenizing furnace with reversing transverse air circulation according to the Mass-flow concept; see also Fig. 5

Flow control

Basically, in the design of the flow circuit a distinction is made between the mass-flow and the nozzle-flow concepts. Which of these two concepts can ultimately be used having regard to the dimensions of an industrial furnace, is decided by the component geometry and the loading pattern. In relation to homogenizing furnaces the two concepts differ essentially as regards the flow directed onto the aluminium logs: the nozzle-flow concept can be used exclusively in continuous homogenizing, because it provides the possibility of addressing a flow directly onto each aluminium log with an individual nozzle (see Fig. 5). This is not the case with all the known designs, and when it is so, it is only appropriate in the heating and cooling zones in order to achieve higher heating and cooling rates that can be adjusted selectively. In such cases the flow impingement speed is substantially higher than 20 m/s.

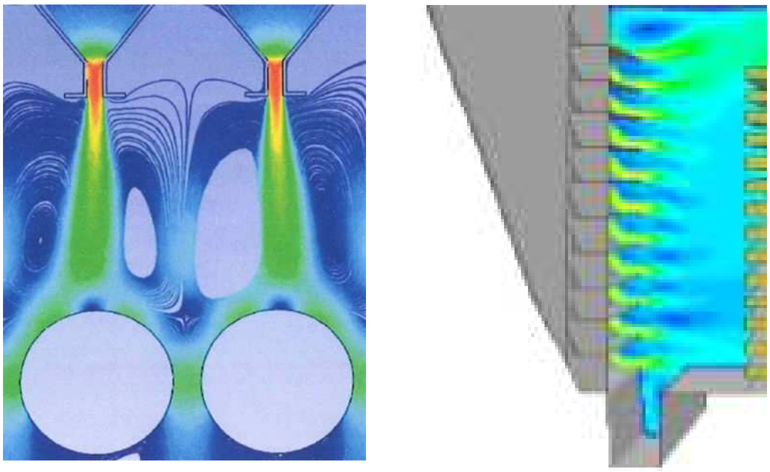


Fig. 5: CFD simulation of a possible nozzle array for the heat-up zone of a continuous homogenizing furnace according to the Nozzle-flow concept (left), compared with the Mass-flow concept (right)

With a stack as illustrated in Fig. 4 in a batch-type homogenizing plant, using the nozzle-flow concept would achieve high local heat transfer only to the positionally fixed, outermost aluminium logs. Since the high incident flow speed cannot be maintained along the path through the stacked charge, the convective heat transfer is reduced and the already mentioned temperature differences relative to the also positionally fixed inner aluminium logs would be produced. For that reason the mass-flow concept, with a lower flow speed (< 10 m/s) but one that is more constant relative to the aluminium logs, is to be preferred. The homogenizing of aluminium logs demands a close temperature tolerance of ± 5 K or better. The temperature difference produced during heating is the smaller, the less is the temperature change of the circulating furnace atmosphere (fluid) relative to the temperature change of the furnace charge. This ratio, the so-termed ‘capacity flow ratio’, is expressed by the following relationship:

$$K = \frac{(\dot{m} \cdot c_p)_{Fluid}}{(\sum_{i=1}^{n} \dot{m}_i \, c_{p,i})_{Gut}}$$

The capacity flow ratio should always be as large as possible, but there are economic limits on this: increasing the capacity flow ratio requires an increase of the flow impingement speed. Whereas the convective energy flow increases approximately according to α ~ V0.8, the power up-take of the fans increases according to PFan ~ V3 so that doubling the flow impingement speed, which achieves a convective energy flow increase of only about 75%, entails an eightfold increase of the fan power. Thus, the effort (e. g. structural space, operating costs) and benefit (heating time, temperature tolerance) always have to be weighed against one another. In practice it has been found appropriate in homogenizing furnaces, with both the nozzle-flow and mass-flow concepts, to adjust the capacity flow ratio to the maximum value that can be obtained economically. The convective energy flow, and in addition the fraction transferred by heat radiation to the surface of the aluminium logs, must be conducted into the core of the material. Whether the heat conduction resistance can be disregarded and the aluminium logs can be regarded as thermally thin and therefore equally tempered, can be checked by a simple formula. Decisive for the difference between the surface temperature and the core temperature is the ratio between the heat transfer resistance and the heat conduction resistance, expressed by the Biot number with heat path L, the heat transfer coefficient a which is the sum of the convection and radiation fractions, and the thermal conductivity λ of the heated body:

$$Bi = \frac{\alpha \cdot d}{2 \cdot \lambda}$$

For $Bi < 0.1$ the heat conduction resistance can be disregarded.

Heating systems

Regardless of the operating mode and of the flow control, homogenizing furnaces can be designed for fuel-firing or electric resistance heating. Which heating method is used depends mainly on the relative costs for electric power and natural gas, and is also increasingly viewed from the aspect of CO2 reduction. The considerations must then also take into account the specific CO2 emission resulting from the particular power mix (respective fractions of nuclear power/fossil/regenerative). The choice of heating method does not influence the homogenizing process from the stand-point of quality. The earlier advantage that electric heating systems enabled a larger control range and therefore better temperature control, has been almost completely compensated by modern gas regulation stretches with a cascaded structure. In the flow circuit the gas burners or heat radiators can be fitted on the suction side or the pressure side relative to the circulating fan. Fitting on the pressure side has the advantage that as a rule a more uniform flow and energy uptake can be ensured at the gas burners or heat radiators, which results in better temperature uniformity in the circulating furnace atmosphere and slightly higher efficiency. Thus, in flow circuits designed for flow reversal particular care must be taken to ensure uniform energy uptake at the heating device on both the suction and pressure sides. An electric resistance heating design has the significant advantage of better energy efficiency; furthermore there is no need for a flue gas chimney. Fig. 6 shows a heat radiator of the type typically used by Otto Junker. When a gas burner is used, to improve the firing efficiency it is standard practice to preheat the combustion air. It is usual to use a gas burner with an integrated recuperator. Fig. 6 also shows a gas burner with a tube recuperator. The preheat temperatures that can be achieved with an integrated recuperator are of the order of 60% of the process temperature, i. e. for equalizing and holding operation during homogenizing a temperature of 350℃ and during heat-up operation up to 400℃. Care must also be taken, for example when an automatic λ-regulator is integrated, that the gas burner should always be adjusted to $1.05 < \lambda < 1.10$. Experience at Otto Junker shows that this can save around 5% of the fuel consumption.

The prerequisite is that the air/gas mixture is continuously adjustable. This gives the added advantage that a control strategy can be implemented in the PLC, which aims to keep the gas burner switched on for as long as possible and thereby further improve the efficiency of the fuel energy used. If sufficient space is available, as a further measure for improving energy efficiency the aluminium logs to be homogenized can be preheated in chambers positioned ahead of the homogenizing furnace, thereby using the exhaust gas enthalpy.

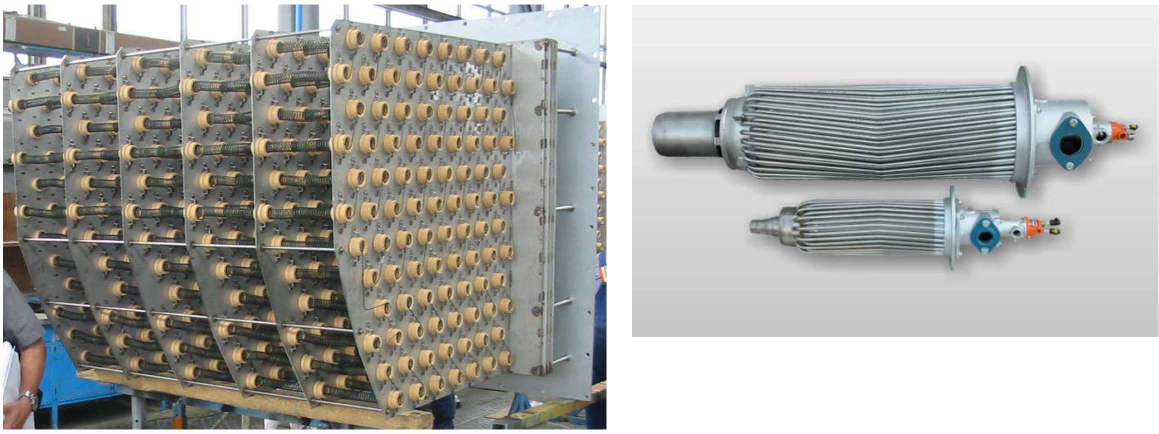


Fig. 4: Heat radiator (Otto Junker design), compared with a gas burner with tube-type recuperator (designed by Wiedemann)

typical energy demand of the two design types

The energy demand is essentially determined by the operating mode of the homogenizing furnace and the boundary conditions existing in each case. The units designed by Otto Junker represent essentially the state of the art. For the two types, Table 2 shows values of fuel consumption and current demand. The most important boundary conditions for this are:

- the homogenizing furnace is thermally insulated
- the homogenizing furnace is leak-proof
- the homogenizing furnace is optimally loaded in relation to its size
- the control of the heating device is optimized to maximize the switch-on time
- with fuel firing, the burners are adjusted so that $1.05 < \lambda < 1.10$.

The fuel consumption is determined in principle by the energy flow that must be supplied to the charge, the exhaust gas losses (≈ 15% to 20% when recuperative burners are used), losses to make up the heat flow through the walls (≈ 300 W/m2 of furnace surface area) and losses sustained during charging.

The balance for electric resistance heated homogenizing furnaces is analogous, but there are no exhaust gas losses. When considering the balance for the two types of heating, however, it must also always be noted that the power of the circulation fans and, in the fuel-fired variant, in addition the power of the combustion air blower are converted completely into heat, and the energy demand is correspondingly reduced by this.

Table 1 shows examples of the corresponding balances. With fuel-fired homogenizing furnaces the use of recuperative burners can reduce fuel consumption compared with cold-air burners, by 15% (see Table 2). Depending on the reference costs for the fuel, conversion pays for itself in a few years; on request the specialists at Otto Junker will prepare individual economic calculations.

Consumption		Fuel consumption		Power demand	
Process step	Consumer	Cold-air burner	Recuperative burner	Old-air burner	Recuperative burner
Heating	Charge heat flow	7,825 kWh	7,825 kWh	-	-
	Circulation fan	-239 kWh	-239 kWh	266 kWh	266 kWh
Holding	Circulation fan	-36 kWh	-36 kWh	40 kWh	40kWh
Heating & Holding	Wall heat flow	556 kWh	566 kWh	-	-
	Combustion air fan	-124 kWh	-103 kWh	138 kWh	115 kWh
Cooling	Circulation fan	-	-	45 kWh	45 kWh
Heating & Holding & Cooling	Switching unit	-	-	45 kWh	45 kWh
Net consumption		7,981 kWh	8,002 kWh	1,108 kWh	1,086 kWh
Cross consumption		11,241 kWh	9,414 kWh	-	-
Specific consumption related top charge weight		245 kWh/h	205 kWh/h	24 kWh/h	24 kWh/h

Table 1: Balances for fuel consumption and electric power demand, for a fuel-fired, discontinuous homogenizing furnace

Homogenising furnace	Discontinuous design	Continuous design
Throughput	3 t/h	
Non-useful charge fraction	10 %	0
Homogenising temperature	585 ℃	
Heat content of aluminium	164 kWh/t	
Holding time	6 h	
Temperature after cooling	< 200℃	
Heat transfer mechanism	Primary: Forced convection. Secondary: Heat radiation	

Directly fuel-fired			
Fuel consumption	Cold air	≈ 245 kWh_{th}/t_{Al}	≈ 236 kWh_{th}/t_{Al}
	recuperative	≈ 205 kWh_{th}/t_{Al}	≈ 198 kWh_{th}/t_{Al}
Power demand		≈ 24 kWh_{el}/t_{Al}	≈ 16 kWh_{el}/t_{Al}
Energy efficiency		61.0 – 71.6%	65.0 – 76.6%

Electric resistance heated		
Power demand	≈ 198 kWh_{el}/t_{Al}	≈ 191 kWh_{el}/t_{Al}
Energy efficiency	82.8 %	85.7 %

Table 2: Fuel consumption, electric power demand and energy efficiency of continuous and discontinuous fuel-fired homogenizing furnaces, in each case compared with an electric resistance heat homogenizing furnace

Summary

In the production sequence of an aluminium smelter the homogenizing furnace is the final heat treatment process before delivery and further processing of the aluminium logs or billets in an extrusion plant. Basically two different plant variants, differing in that they operate continuously or discontinuously, have become established on the market. Both types fulfill the metallurgical requirements with sufficient accuracy. When making a choice, the heating equipment and heating concept are not decisively important. Unless the space available is a factor, the flexibility required by the user is the essential deciding criterion: frequent changes of format, alloy and temperature encourage the use of the discontinuous design, but if the role of flexibility in the production sequence is subordinate the advantages of the continuous variant can be put to good use. As a complete supplier of both the variants Otto Junker is a competent and dependable partner for its customers when selecting the most economic variant and determining its size.