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Publication

Energy-optimised route from aluminium scrap to extruded semi-finished products

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In light of the European Union's demanding CO_2-reduction targets and indirectly rising energy costs, European aluminium semis producers are exposed to increasing competition pressure. For almost a decade now German plant manufacturing industry in particular has very successfully been exporting production plants, especially to Asia. But with every exported production unit there is also a transfer of know-how. Particular contributions to this are made by joint ventures or the employment of consultants from western Europe. In the medium term it is to be expected that as regards saleable aluminium semis, in relation to quality and productivity and with conditions otherwise the same (e.g. materials and tools used) there will no longer be significant differences and Asiatic manufacturers will increasingly move into other export markets. As a direct result sales prices will fall. At the same time European manufacturers of aluminium semis are burdened by comparatively high personnel, natural gas and electric power costs, and in particular by the fact that the cost of energy is expected to rise by more than the rate of inflation. Falling prices on the one hand and rising costs on the other hand have a sustained downward effect on profits, which restricts the scope for investments. However, to ensure the necessary innovative advances investments are urgently needed. That aspect provides reason enough to concern oneself with energy potentials, so the focus of this article is on costs for thermal energy converted essentially from gaseous fuels such as natural gas or propane.

However, for plant manufacturers and aluminium semis producers the optimisation of operating costs is no new challenge. Thus, the consumption of thermal energy in foundries and extrusion plants could be cut by roughly 14%, simply if the heat process equipment in use today all conformed with the most advanced state of the art [1].

Thus, the political aim of cutting CO_2 emissions has only increased public awareness of energy efficiency. High energy efficiency levels of production plants have for many years been the common objective of engineers working in the contexts of both plant manufacturers and plant operators. The fact that many existing approaches toward improving energy efficiency are not being implemented is evident from a consideration of the determinants of an economics computation: those include investment costs, which on the assumption of a particular interest rate have to be set against operating cost savings. The break-even point of the function obtained is the amortisation time.

If investment costs are regarded as fixed, then the remaining parameters for further consideration are operating cost savings and amortisation time, and it then becomes clear why the energy efficiency of the equipment stock lags behind the technical possibilities: the amortisation periods expected by investors – as a rule, one to three years – are either too short and/or energy costs are still too low.

In this article we shall consider what saving potentials in thermal process technology could still be developed if there were a possibility of building a new continuous casting plant and extrusion plant 'from the ground up'. In this the limiting factor is economy, i.e. the possible approach of replacing thermal energy by electrical energy is ruled out because in that way, depending on the current mix, CO_2 reduction would be achieved in operational terms but not economically.

Thermal process equipment in foundries and extrusion plants – the state of the art

The present state of the art serves as a basis for the analysis, inasmuch as it is assumed that the individual thermal process units in operation today have already undergone measures to reduce their energy consumption:

- The combustion air of the burners used is preheated by regenerators or recuperators (centrally or de-centrally)
- From the instrumental and control standpoint the regulation of the burners is designed for wide control ranges (1:10 or more) and long periods of being switched on (reduction in the number of switching operations)
- Combustion takes place, for example thanks to the use of λ-probes, always as close as possible to the stoichiometric air ratio ($\lambda = 1$)
- The loading pattern and filling level ensure that the thermal process unit is operated close to its design point, i.e. its nominal performance rating
- Design measures to optimise furnace efficiency[1] (structure of the insulation, avoidance of apertures, the use of appropriate seals) are adopted, and maintenance work is carried out carefully.

Table 1 shows the thermal energy demand that can be expected from modern thermal process equipment if the above-mentioned assumptions are fulfilled [1]. The values are referred to the mass of aluminium used. It is also assumed that the alloys processed can predominantly be made with the use of recycled material or aluminium procured from outside 'as necessary'. The consideration also does not take account of high-strength components that have to be heat treated (such as by T6 annealing).

Table 1: Thermal energy demand in the strand casthouse and the extrusion plant

Thermal process unit	**State of the art** **'Primary exhaust gas utilisation'**	**Energy demand** **(kWh_{th}/t_{Al})**
Two-chamber hearth furnace	Combustion air preheating with regenerator, if necessary using the heat content of organics	660 – 700
Casting/holding furnace	Combustion air preheating with recuperator	30 – 50
Homogenising furnace	Combustion air preheating with recuperator	195 – 205
Billet heating furnace	Combustion air preheating with recuperator and preheating of the charge	175 – 215
Aging furnace	Combustion air preheating with recuperator	75 – 85
Thermal energy demand		1,135 – 1,255

[1] From the furnace efficiency the colloquialism 'idle value' is derived

The objective is to optimise the energy demand in the strand casthouse and the extrusion plant. As an approach toward achieving this, in what follows the available options will be discussed for combining thermal process units with one another in such manner that heat energy, once introduced, can be used in as many process steps as possible.

Casthouse production area

At the beginning of the process chain is the melting furnace. In view of the need for economically viable energy optimisation, as many strands as possible should be produced from secondary aluminium, i.e. aluminium scrap. For that purpose it is best to use a two-chamber hearth furnace (Fig. 1) as the recycling aggregate. In 2010 aluminium production in Europe was typically characterised by proportions of 1 tonne of secondary metal to every 3.5 tonnes of primary aluminium. According to the investigations by *Quinkertz* [2], until the energetically optimum proportion of around 75% is reached there is still considerable useful economic potential for aluminium recycling (Fig. 2). Beneficial in addition to the favourable energy balance[2] are the waste collection systems which operate comparatively well in Europe, thanks to which the availability of suitable scrap can be ensured.

Fig. 1: Example of a typical recycling furnace (Otto Junker/Thermcon design)

[2] Producing one tonne of primary aluminium demands a consumption of around 13,500 kWh_{th+el}/t_{Al} [3], whereas a tonne of secondary aluminium demands only a fraction of that, see Table 1.

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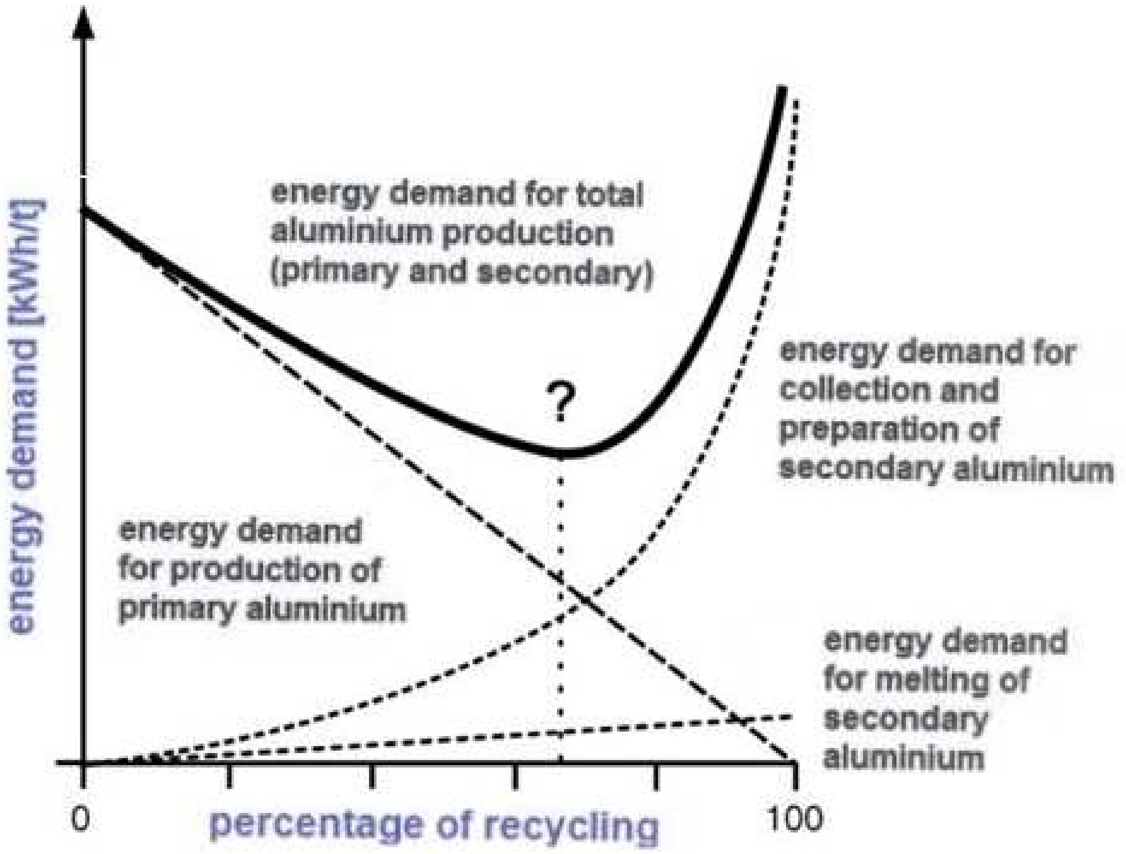

Fig. 2: Qualitative variation of the total energy costs for aluminium production (primary and secondary), *Quinkertz* [2]

The state of the art is to equip two-chamber hearth furnaces with regenerator burners. For economical operation these require exhaust gas temperatures higher than 750 ℃. The relative air heating that can be achieved with regenerators amounts to ε ≈ 0.8, which means that about 80% of the heat content of the exhaust gas can be recovered. Consequently the preheat temperature of the combustion air is 800 ℃ when starting with a typical hot-chamber temperature of about 1000 ℃ (Fig. 3). After the re generator there is still available an exhaust gas heat content of approx. 200 kWh_{th}/t_{Al} at a temperature of 150° to 250 ℃.

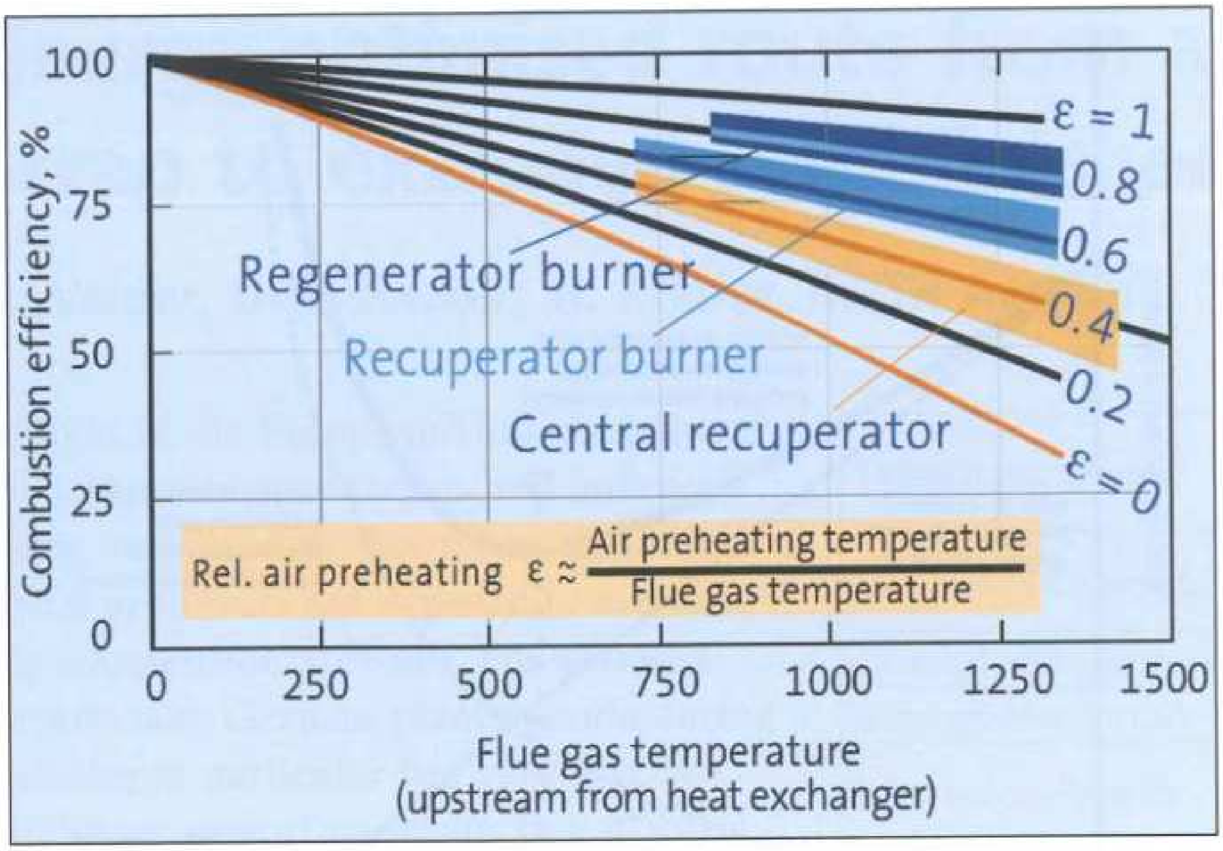

Fig. 3: Furnace technological efficiency (natural gas H, excess air 15%) [4]

The melting furnace is usually followed by a holding or casting furnace. The need for this depends mainly on the metallurgy, and the energy consumption almost exclusively on transfer losses and hot-holding times. Thus, both of the two last-mentioned factors must always be kept as small as possible.

Since neither cold-air burners, which are still used today, nor regenerator burners can be used in a holding/casting furnace to optimum energetic effect, the use of recuperator burners is to be recommended. The resulting residual exhaust gas heat content of only 20 kWh_{th}/t_{Al} at about 350 to 400 ℃ can only be used rationally in an exhaust gas combination with the melting furnace.

Clearly there is a possible association between the continuous casting plant and the downstream homogenising furnace (Fig. 4).

Fig. 4: Example of a typical billet homogenising system consisting of two batch furnaces and a cooling chamber (Otto Junker design, as in the following photos)

A widespread practice is to bring the strands into the homogenising furnace only after they have cooled to room temperature. On the one hand this practice arises from understandable infrastructural and production planning reasons, and on the other hand there are also restrictions of a thermo-process technological nature: for space and time related reasons homogenising furnaces are operated at excess temperatures at least until the beginning of the equalisation phase. A prerequisite for this is that the cast aluminium strand should be introduced into the homogenising furnace as isothermally as possible.

In the first place, however, from a metallurgical standpoint it is not critical whether the isotherm amounts to 300° to 350 °C instead of room temperature, and secondly, from the standpoint of thermo-process technology it is unproblematic to carry out a homogenising process with excess temperatures of less than ±10 K. Accordingly the two operating methods, batch and continuous, have to be compared against one another. At first sight it seems advantageous for the batch method that the strands cast in one batch can then also be homogenised in a batch. To keep the waiting times after casting as short as possible and thereby to maintain as high as possible starting temperature, it may be necessary compared with the conventional production sequence and for an otherwise equal annual production to provide more annealing and cooling capacities. In particular, the cooling chamber could be used as a buffer – if adjusted to below 350 °C.

The higher one-off investment (number of homogenising units, space occupied) needed for this is set against the permanent halving of the energy consumption: with a charge temperature of 300 °C, in a typical homogenisation half the amount of energy previously used is saved, namely approx. 100 kWh_{th}/t_{Al}. The larger amount of space occupied is a disadvantage. With the production of homogenised strands the task of the casthouse is accomplished and the interface to the downstream extrusion plant is formed as a rule by a (cold) strand store, because the typical batch sizes of (vertical) casting and homogenising in a batch process do not match the typical extrusion production runs.

Extrusion plant production area

Having regard to the aspect of optimising energy use, the question of how real production continuity can be achieved between the casthouse and the extrusion plant that comes after it. Ultimately, the aluminium strands delivered for extrusion are already re-heated, typically to 480 ℃, in a first working step before deformation. Considering, however, that after the homogenisation process, from the metallurgical standpoint it is only necessary to cool the metal to 300 ℃ instead of to room temperature, it becomes really obvious to look at the link to the extrusion plant. This approach is not new, but it has also not been implemented widely before now and it can therefore be worth the trouble to discuss this against the background of constantly developing technology.

Assuming a capacity of about 4 t/h and 8,000 working hours a year, a casthouse produces about 32,000 tonnes of aluminium strands a year. In the subsequent extrusion plant that quantity demands the operation of two extrusion presses. In practice it is assumed that the aluminium profiles produced will be made not only from different alloys (according to the requirements of their subsequent use) but also from different strand diameters (to limit the degree of deformation). It must also be borne in mind that depending on the size of an order, only one strand of a given alloy may be needed. These boundary conditions set the requirement that it must be possible at any time to deliver to the extrusion plant individual strands containing residual heat, but having different diameters and made of different alloys.

Fig. 5: Example of a typical vertical magazine used as a cold store

The conversion of the cold vertical magazine into a hot, or heat-retaining vertical magazine is a typical engineering task, i.e. there is no obvious reason to doubt its feasibility.

However, it should be borne in mind that the temperature uniformity of the heated strands is not very good. Both the frequent access to the vertical magazine (5 to 10 times an hour) and its spatial extension (≈ 400 m^3) have a negative effect when exhaust gas is fed in as the energy carrier at a low dynamic pressure for keeping the temperature up over a large area. From this the boundary condition is derived that the heating furnace upstream from the extrusion press must be capable of equalising inhomogeneous entry temperatures.

The use of conventional heating furnaces, in which the heat transfer takes place by the direct action of flame with a correspondingly higher excess temperature, is not suitable for this purpose owing to the risk of melting. In contrast, a convection furnace is perfect for the purpose.

In that case the heat transfer takes place at temperatures slightly above the deformation temperature required, so that even if boundary conditions are unfavourable a temperature tolerance of ±5 K can be guaranteed. Here too, from the aspect of energy efficiency there is at present no more suitable aggregate [5].

From the standpoint of energy optimisation, in summary, it can be said that the heating of aluminium strands held at about 300 ℃ after homogenising instead of being cooled, to a first approximation results in a saving of 60% of the previous energy consumption, namely around 105 to 125 kWh/t_{Al}.

The convection furnace (Fig. 6) is heated by recuperator burners and operated at approximately 500 ℃. With a relative air preheat of $\varepsilon = 0.6$ the exhaust gas temperature still amounts to about 200 ℃ and the exhaust gas heat content at least 55 kWh_{th}/t_{Al}. Owing to the temperature after the recuperator this exhaust gas cannot be used to keep the magazine hot and should therefore be returned to the exhaust gas system in the casthouse.

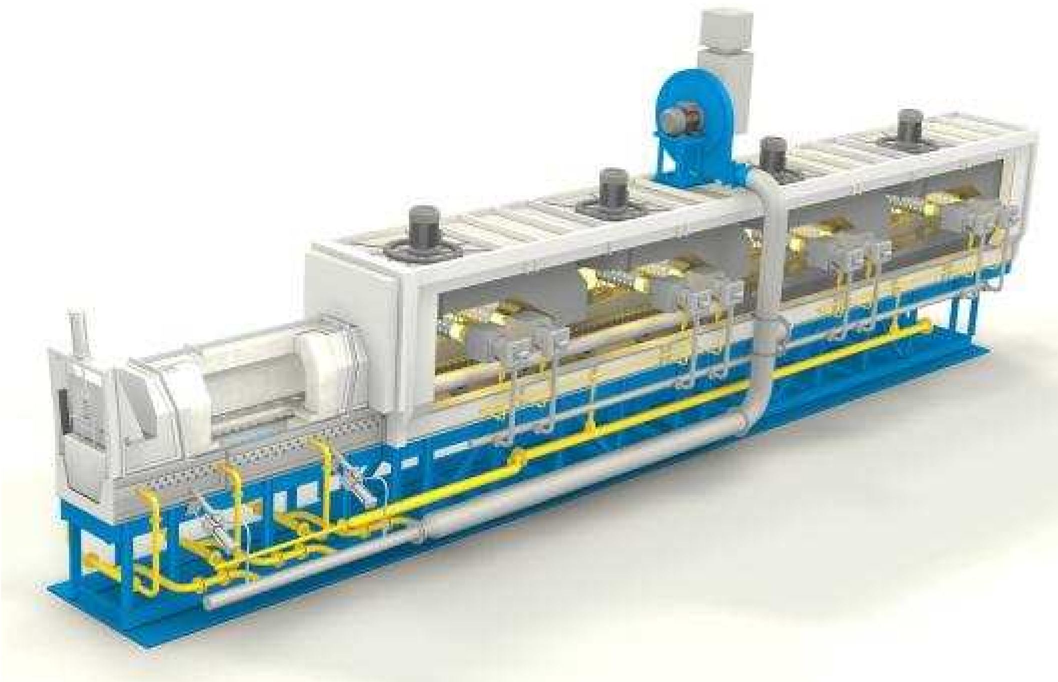

Fig. 6: Combi-Gas convection furnace (patent applied for)

From the above it follows that the vertical magazine has to be kept hot with the exhaust gases from the homogenising furnace: here, even after the supply of aluminium strands hot from casting, an exhaust gas heat content of approx. 85 kWh_{th}/t_{Al} is still available. The recuperator should be designed for an exhaust gas temperature of 320 ℃, to cover energy losses in the vertical magazine.

Theoretically, this exhaust gas, with a heat content of around 60 kWh_{th}/t_{Al}, could then be returned to the existing exhaust gas system at a temperature of 300 °C.

Finally, it still remains to consider the ageing furnace (Fig. 7): at first sight it seems reasonable to suppose that the section temperature after emerging from the extrusion press (about 500° to 550 °C) in fact supplies some heat to the ageing furnace. Closer consideration, however, shows that this optimisation route is not effective: for metallurgical reasons it is very often necessary to cool the sections very carefully and/or subsequently to stretch them, so that after the run-out system the extruded sections are stacked cold in racks and then taken to the ageing furnace.

There, the aluminium profiles have to be heated to 185 °C and held at that temperature for several hours. Owing to the low process temperatures and the associated risk of falling below the dew-point (staining), ageing furnaces are indirectly fuel-fired and this, mostly, with cold-air burners. Depending on the surface load of the radiator tube the exhaust gas temperature after the burner is up to 280 °C. To optimise energy utilisation the medium of choice is to use recuperator burners, since energy efficiency increases, the closer is the link between the primary process and the measures for improving efficiency. Behind the recuperator the temperature can still be expected to be around 120 °C. Although the energy saving achieved then amounts to only 10 kWk_{th}/t_{Al} in absolute terms, that is more than ten percent of the previous energy consumption.

Fig. 7: Example of a typical ageing furnace

Further use of the exhaust gas – for example in the proposed exhaust gas system – is not appropriate in light of the temperature level after the recuperator.

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The effect of the exhaust gas system can now be estimated now that all the fuel-heated thermo-process units have been considered: in total, from the recycling furnace, the holding/casting furnace, the heated vertical magazine and the billet heating furnace an exhaust gas heat content of 335 kWh_{th}/t_{Al} is obtained, at a temperature of approx. 250 ℃ with adiabatic mixing.

Only 30 kWh_{th}/t_{Al} are needed for preheating the scrap supplied to the recycling furnace to 100 ℃ and drying it. Now, instead of storing the scrap coming from within and outside in heaps, a scrap bunker heated by the energy flow from the exhaust gas system should be provided. A possible approach would be to set up a system of circulating 'pick-and-place' charging troughs: in a cyclic system these would be charged with incoming scrap, parked automatically in the heated bunker, and as necessary or after an appropriate dwell time, removed for charging the recycling furnace.

Possible result

For the foundry and extrusion plant production sector various approaches have been discussed for reducing energy demand:

- spatial combination of the casthouse and the extrusion plant
- construction of an exhaust gas system for preheating the scrap to 80 ℃
- beginning homogenisation at 300 ℃ instead of from room temperature
- beginning billet heating at 300 ℃ instead of from room temperature
- using recuperator burners in the ageing furnace.

The measures described above lead to an energy saving of 245 to 265 $kWh_{th}/t_{Al,}$, which corresponds to 22% (Table 2). With an average industrial natural gas price (EU 28) of 0.039 €/kWh_{th} [6] and the assumed annual production of 32,000 tonnes, in the casthouse and extrusion plant energy costs between 305,000 and 330,000 euros can be saved.

Table 2: Thermal energy demand in the continuous casting plant and the extrusion plant, after optimisation

Thermo-process plant	**Saving (kWh_{th}/t_{Al})**	**Optimised energy demand (kWh_{th}/t_{Al})**
Two-chamber hearth furnace	30	630 – 670
Casting/holding furnace	none	20 – 40
Homogenising furnace	100	95 – 105
Billet heating furnace	105 – 125	70 – 90
Ageing furnace	10	65 – 75
Thermal energy demand$_{opt.}$	245 – 265	880 – 980

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Summary

The analysis of potentials for saving thermal energy was carried out on the assumption of a ‘greenfield’ investment. It has been shown that there are a series of measures which could be implemented when planning a new plant. Nevertheless in individual cases higher investment costs have to be allowed for, which become economical only if longer amortisation times are acceptable. Alternatively, only (even) higher energy costs would produce the necessary incentive for action. The first approach is to be preferred – lower energy needs reduces demand and lowers the price.

At the same time it is clear that to make use of the potentials whose existence is not in doubt, requires interdisciplinary collaboration between various fields of engineering science. However, it must be admitted that at the locations existing today, restrictions are in force which enable only some of the measures described.

For the sake of completeness, there is an important aspect which should not be left unmentioned: the above considerations imply that between the recycling furnace and the ageing furnace some 32,000 tonnes of aluminium a year are processed without losses. This, of course, is not the case. In fact, for the actual sale of 32,000 tonnes of profiles as a rule more than 42,000 tonnes of aluminium have to be charged into the recycling furnace. In the form of combustion loss, overfill losses, strand offcuts, billet and extrusion discards, profile scrap and rejects, it is usual for more than 30% of the material originally charged to be returned back into the cycle. That fact often is the first to justify the operation of a casthouse in combination with an extrusion plant. To that extent, improving productivity also has high potential for reducing energy demand.

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