

UNDERSTANDING OF SUSTAINABLE PRIMARY AND SECONDARY ALUMINIUM PRODUCTION

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Abstract

Production and use of aluminium are determined by the physical properties of this metal. In many applications exists a strong competition of substitution by steel and plastics, which is today less dominated by material aspects and more by environmental politics. The problems of aluminium production are located in the high demand of electric energy, the solid residues and the atmospheric emissions. Concerning this, as examples of low waste and low energy technologies are named the use of the tube reactor, the fluid bed calciner, the high current electrolysis and melt refining by inert gases. Comparing primary and secondary aluminium production by an inventory, secondary metal shows clear advantages, but pot-line material is also needed to cover the demand for pure metal, metal losses and the world-wide increasing demand. The sustainability of primary and secondary aluminium production is firstly to reach three aims simultaneous: Lowering the energy demand, lowering amounts of residues and emissions and improving metal quality. Therefore the practical realisation of a sustainable aluminium production is no invention of the nineties but basic part of normal technological development.

Keywords

Aluminium production, energy supply and consumption, efficiency, residues and emissions, low waste and low energy technologies, sustainability

1. Introduction

Today aluminium is one of the most important metals for use because of its excellent mechanical and physical properties. In many applications, specially in the field of traffic and packaging, exists a strong competition of substitution by steel and plastics. With the increasing ecological awareness of the past ten years this competition is less dominated by material aspects but more by environmental politics.

The primary and secondary production of aluminium is also determined by the physical and chemical properties of this metal, particularly by the high affinity to oxygen. For this reason during the metallurgical treatment of bauxite the refining (production of high purity alumina) takes place before reduction into liquid metal. Concerning the recycling this means a separation of the scrap into different alloys and cleanness before melting. Beyond that, the high reduction potential causes a high energy requirement of 13 to 15 kWh/kg Al for primary aluminium production from bauxite or other oxidic ores.

So power supply plays the important part when a new location for an aluminium smelting plant has to be found and most of the aluminium electrolyses are located beside power stations to minimize losses of power transfer.

Moreover, the different steps of processing the bauxite into aluminium metal are not carried out at one site. Numerous Bayer-digestion plants are located beside the mineral deposits and the aluminium electrolyses can be found in countries with big energy capacities. This causes a high amount of mass transport between the deposit, the digestion plant, the electrolysis and the consumer. Otherwise the main amount of residues, specially the red mud, is obtained and dumped near the deposits in tropic regions.

2. Ecological aspects of primary and secondary aluminium production

The first item of ecological discussion at the primary aluminium production is the quality of bauxite. Aluminium occurs in several mineral components and their mixtures depending on the respective deposit. In addition, the type and concentration of accompanying elements can be different. The type of mineral is estimating the temperatures and caustic soda concentrations needed for the Bayer digestion process.

The accompanying elements of aluminium minerals in the bauxite, especially Fe, Si and Ti, determine the amount of red mud, the losses of Al_2O_3 and Na_2O and technical problems like accretions of silicates. The amount of 0.4 - 1 t/t Al_2O_3 of red mud is not reprocessed but frequently dumped beside the digestion plants. Table 1 shows conditions of the Bayer process for european and tropic bauxite. Further residues are drosses, used furnace linings and filter dusts.

Table 1: Conditions of the Bayer process for european and tropic bauxite [1]

PROCESS DATA	EUROPEAN BAUXITE	TROPIC BAUXITE
temperature of digestion [°C]	220	160
Na_2O -concentration [g/l]	250	150
efficiency of digestion [%]	90	98
amount of red mud (dry) [t/ Al_2O_3]	0.95	0.38
aluminium yield [%]	85	92

For secondary aluminium production the quality of scrap plays the important part because only clean and pure classified material can be remelted without losses of metal quality. To ensure this, scrap pretreatment has to separate different alloys and to remove contaminants as well as nonmetals before melting. But, because of the high difference between the energy required for primary and secondary aluminium production an economic recycling also of low quality scrap is possible, see figure 1 [2].

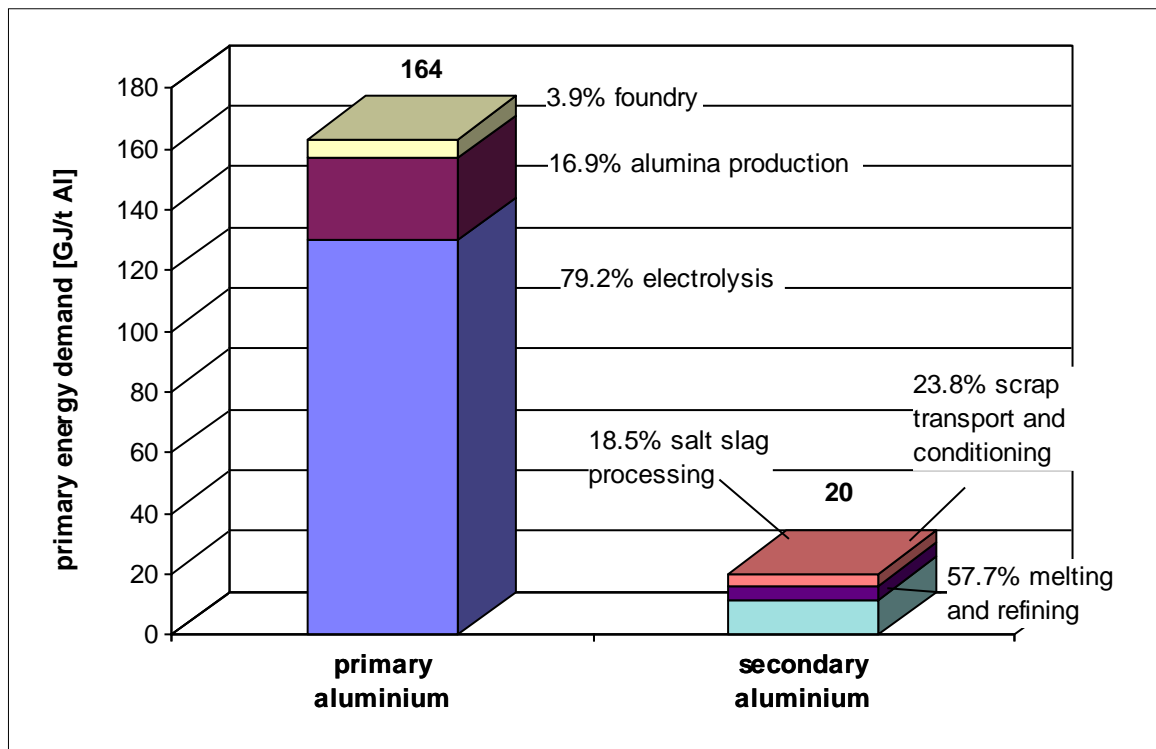


Fig. 1: Primary energy required for the aluminium production in Germany per 1 t Al [2]

The main part of energy required for the primary aluminium production is used in the reduction cells (79%), it is followed by the alumina production (17%). The shown accumulated demand of primary energy for aluminium production is not containing bauxite mining and overseas transport. Here have to be added about 10 GJ/t Al. For secondary aluminium production 47% of the total energy demand are required for melting itself and 11% for refining and casting. The share of transport is with 6% relatively high because the scrap is coming up decentralized and causes different transport stages. In comparison the percentage of transport energy for primary aluminium production is less than 0.2%.

To calculate accumulated energy requirements, the typical efficiency of german mixed power supply of 35.3% have been regarded. Providing for fossil fuels causes an additional efficiency of 91.5%. Thus, the overall efficiency comes to 32.2% [2].

Figure 2 shows the amount of solid residues referring to 1 t unalloyed aluminium. 3650 kg arise for primary aluminium production from european bauxite. The alumina production has the main share of 87%, which consists of red mud with a water content of 40-50% [3, 4]. Using tropic bauxite with a lower iron content the red mud amount decreases to 1.6 t per t aluminium. Several attempts to reprocess this residue still have no success. Further solid residues come from power supply for the electrolysis and consist mainly of ashes from coal fired power stations.

For secondary aluminium production 400 kg solid residues only arise per t Al. This amount can be lowered to 95 kg/t Al by utilization of the oxide residue, for example in the cement industry. 70% of the residues from the melting process are dusts from bag filters behind delaquering, melting and refining units.

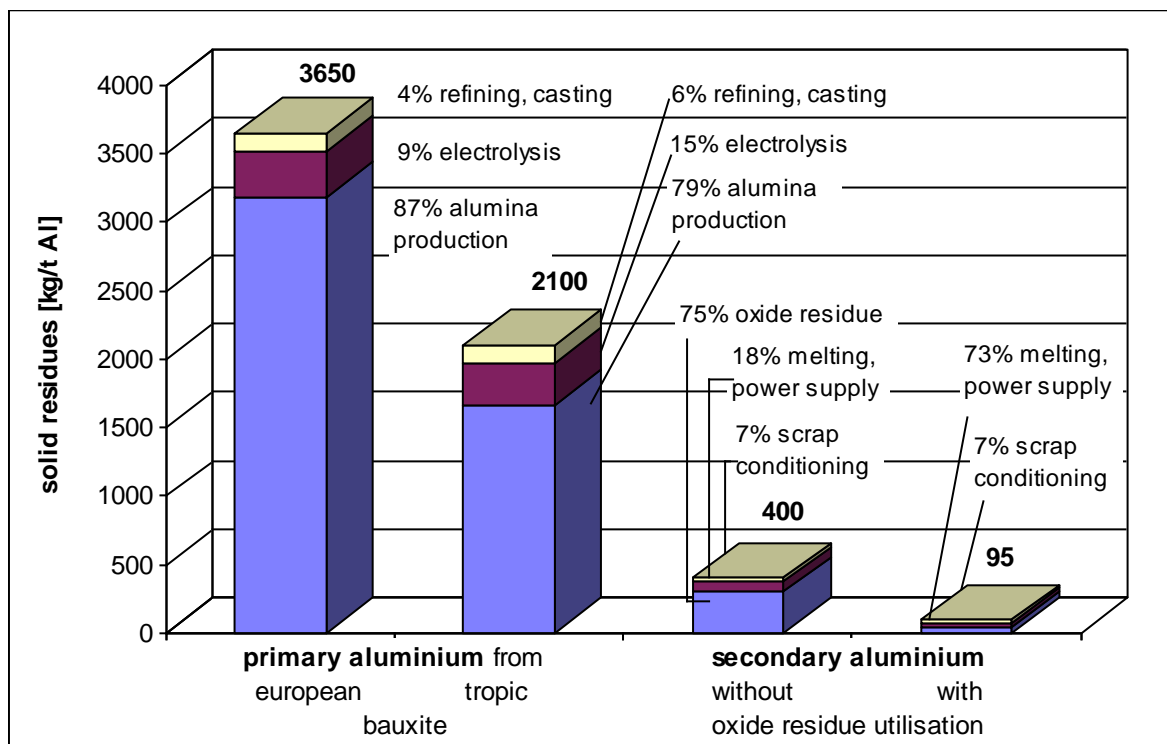


Fig. 2: Amount of solid residues for the aluminium production per 1 t Al [2]

These dusts are still dumped, reprocessing is done only to a small extent as long as dumping will be less expensive. Regarding to the composition of filter dusts the insert materials and the gas treatment techniques are of prime importance. The main component is mostly unreacted slaked lime which is added as chemisorbant. Beside chlorides, fluorides and secondary formed Al_2O_3 , $CaCl_2$ and $CaSO_4$ the flue dust contains metallic aluminium, free carbon and organic compounds, also polychlorinated dibenzodioxines and -furanes (PCDD/F) [5, 6].

Table 2 shows a comparison of all the arising residues. Drosses and salt slags are reprocessed and their metal and salt content are reused. Concerning this, only red mud, used furnace linings and filter dusts are real residues.

Table 2: Comparison of residues from primary and secondary aluminium production [7]

PRIMARY ALUMINIUM (kg/t Al)	red mud 1500 - 2000	used furnace linings ca. 30	dross ca. 20
SECONDARY ALUMINIUM (kg/t Al)	salt slag 300 - 500	filter dust ca. 20	used furnace linings ca. 2
SALT SLAG PROCESSING (kg/t slag)	Al concentrate 50 - 80	oxide residue 300 - 450	dross ca. 30
			melting salt 500 - 750

In spite of sufficient salt slag processing plants the slag may be leached for its potassium chloride content only with the remaining 77% of sodium chloride and oxides dumped. This is clearly not sustainable.

After aluminium reduction in the electrolysis or scrap melting in hearth or rotary furnaces the liquid metal is still not in a castable condition. A gas treatment is necessary to remove alkali and earth alkali metals as well as dissolved hydrogen. The most effective gas used is chlorine or mixtures of chlorine with nitrogen or argon. Only to remove hydrogen from liquid aluminium rinsing with inert gases without chlorine may be sufficient. In contrast to that, hexachlorethan mainly used in small foundries for refining seems to be critical.

The overall atmospheric emissions from primary aluminium production are 204 kg/t Al (see figure 3). 85% come from power supply from fossil fuels. The emissions consist (beside carbon dioxide) mainly of sulfur and nitrogen oxide and dust. Only small percentages are process caused emissions like fluorine and its compounds from aluminium electrolysis and chlorine from refining. Further critical components are carbonfluorides generated especially during the anode effect. The total amount regarding to reduction cells with prebaked anodes and central feeding is about 0.1 kg C_mF_n /t Al with a C_2F_6/CF_4 ratio of 1/10.

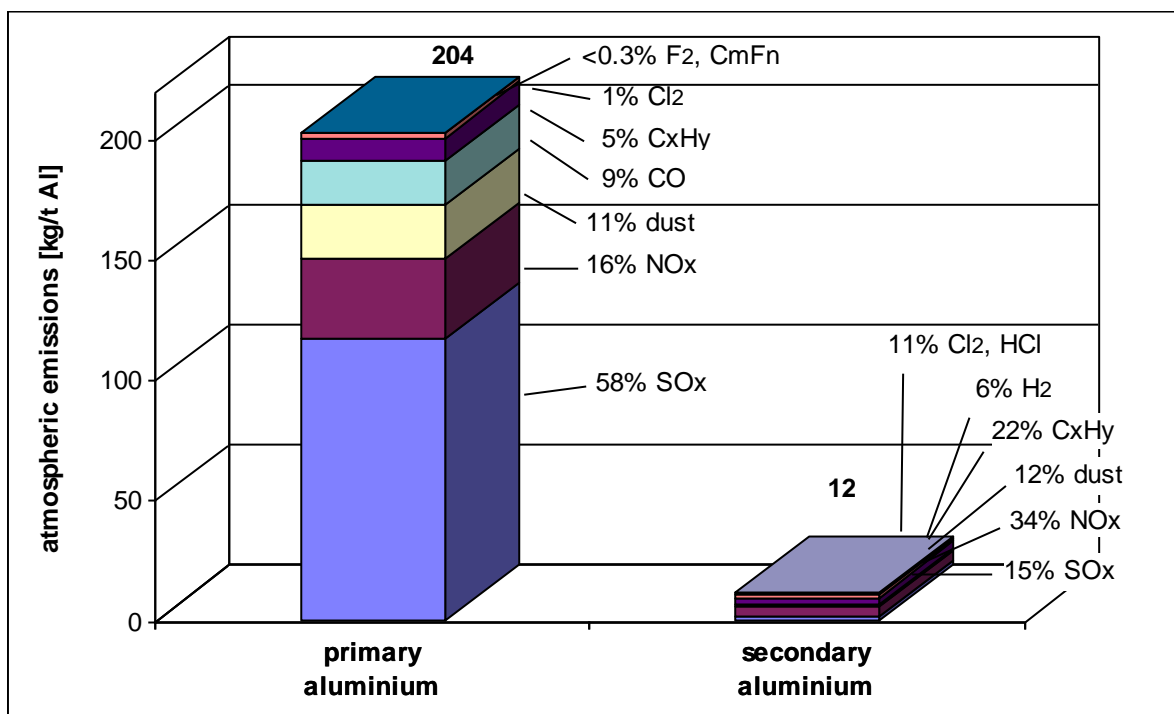


Fig. 3: Atmospheric emissions during aluminium production per t Al (without CO₂) [2]

With 12 kg/t Al the atmospheric emissions during secondary aluminium production are substantially lower. 50% come from combustion of fossil fuels in power stations, 20% from the melting process itself. Because of pyrohydrolysis in the offgas Al₂O₃, HCl and HF are generated from AlCl₃, AlF₃ and moisture [6]. Waste gas treatment is done by chemisorption with slaked lime followed by bag filters. The dust emission comes from diffuse sources,

where uncomplete exhausting is mainly responsible. The amount of upcoming dioxines from recycling is about 1 ng TE/Nm³ in the offgas.

3. Low waste and low energy technologies

The first step of bauxite processing is the digestion in concentrated caustic soda. In contrast to the good digestable tropic bauxite, which consists of easy soluble (160 °C, 150 g/l Na₂O) gibbsite (α -Al(OH)₃) böhmite (α -AlOOH) from european bauxite has to be digested at higher temperatures and higher caustic concentrations (220 °C, 250 Na₂O). Figure 4 shows steam requirements for heating the different reactors [1]. Because of this and other disadvantages like the red mud problem european bauxite is hardly used any more in germany (compare table 1).

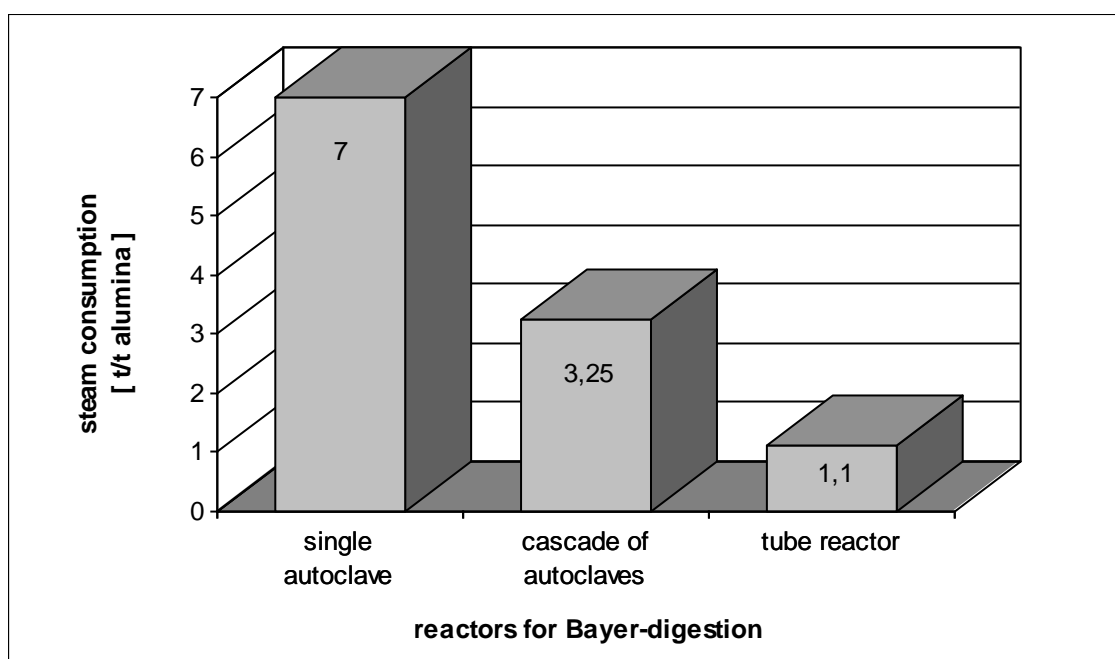


Fig. 4: Steam consumption of different reactors for Bayer- digestion [1]

Today's technology is the digestion with autoclave cascades although the tube reactor only requires one third of energy. This big difference is caused by better heat transfer by turbulent mixing, short reaction times and the decreasing amount of high temperature steam consumption as shown in figure 5 [8].

After separating the red mud from the solution aluminium hydroxide is precipitated from the liquor and in the next step calcined to alumina. Figure 6 shows the saving of energy obtained by introduction of the circulating fluid bed calciner.

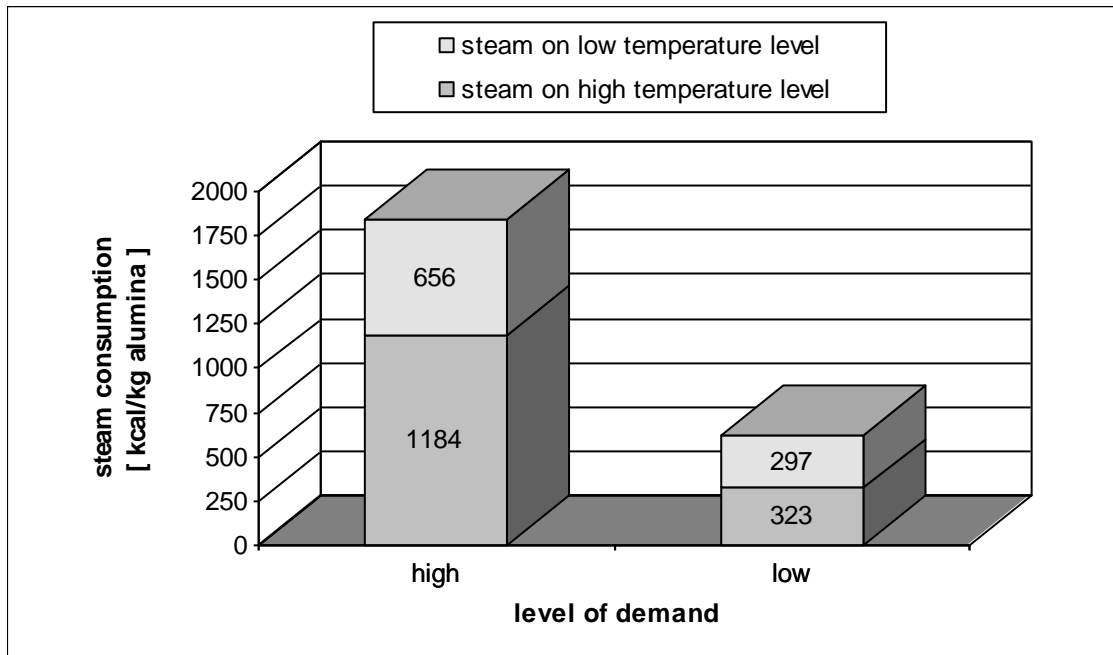


Fig. 5: Part of high and low temperature steam requirement for the digestion process [8]

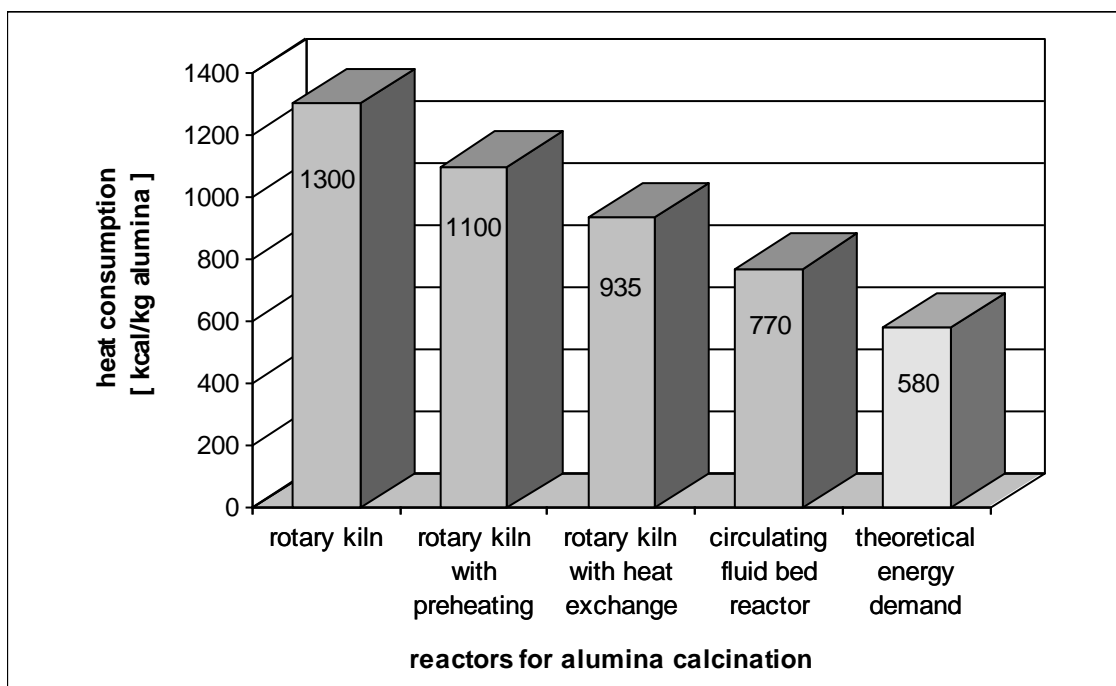


Fig. 6: Heat consumption of different reactors for alumina calcination [1]

The development of the aluminium reduction technology is shown in table 3. By the use of modern high current reduction cells with low current density the necessary cell voltage can be lowered and the current yield can be increased in such an extent that a power demand of 12 kWh/kg seems to be realistic. Furthermore lowering the cell temperature and the contemporary formation of carbon monoxide will decrease the amount of anode gas and carbon consumption.

Table 3: Process data of aluminium electrolysis per kg Al

	TODAY ATTAINABLE	IN FUTURE ATTAINABLE	THEORETICALLY POSSIBLE
direct current (kWh)	14	12	10
alumina (kg)	1,92	1,90	1,89
carbon anodes (kg)	0,41-0,47	0,41	0,33
cell size (kA)	180-250	300	-
current density (A/cm ²)	0,8	0,6	-
anode gas (Nm ³)	0,7-0,75	0,7	0,56

Up to now the aluminium industry has reduced the emission of carbon fluorides to 0.1 kg/t Al, a further reduction to 0.03kg/t can be reached by minimizing the anode effect to 1 per 48h. The gas treatment of the melt before casting is done conventionally in special hearth furnaces with gas lances. In the meantime in-line refining with gas feeding stirrer units between melting furnace and tundish has become usual. To reduce the chlorine emission below the german maximum workroom concentration (MAK) it is possible to use such units.

4. Summary and outlook

Comparing primary and secondary aluminium production secondary metal shows clear advantages concerning energy consumption, residues and emissions. This shows the importance of aluminium recycling.

A disadvantage of the recycling is the impossibility of pure metal production. Only by processing pure classified and clean scrap the economical and ecological advantages of aluminium recycling can be combined with the high qualitative pretensions. Because of this the separate collection and the improved conditioning of upcoming scrap is an important task. Moreover, the temporal displacement of obtainable old scrap and the production of casting alloys causes a deficit of available metal. This deficit is covered with metal from wrought alloy recycling. So the recyclers still have a free scope for alloy adjustment during processing of high alloyed scrap.

According to that, it is clearly wrong only to propagate aluminium recycling because primary aluminium will also be needed in future to cover

- the demand of pure metal, for example for foil production,
- the increasing demand because of worldwide increasing use,
- lacking amounts because of long durability and
- losses during processing, use and recycling.

Sustainability of primary and secondary aluminium production is to reach three aims simultaneously: Lowering the energy demand, minimize residues and emissions and improve

the metal quality. The presentation of low energy technologies shows big steps have already been done. Similar big steps can not be expected soon because in some cases the technical development approaches theoretical boundaries. Therefore the practical realization of a sustainable aluminium production is a basic part of technological development of the last 25 years. It seemed us important to publish this to make the industrial efforts credible.

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