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# THE RECYCLING OF HIGH MAGNESIUM ALUMINIUM ALLOYS-ESTIMATION OF THE MOST RELIABLE PROCEDURE

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## Abstract

Aluminium is one of the most recyclable materials. Namely, the properties of aluminium are not affected by the recycling and reuse, thus enable that high value of the metal is maintained after reprocessing. The re-smelting process of secondary aluminium from scrap consumes only about 5 % of the energy required for the production of primary aluminium. The special properties of the metal aluminium require sophisticated processing of different types of aluminium containing materials prior to re-melting and refining. Aluminium and other materials in composites have to be liberated and afterwards separated from each other. Moreover, residues deriving from the re-melting and refining process such as salt slag or dross have to be treated.

In the area of ship dismantling, development of improved technologies for extraction, treatment, disposal and recycling of materials and other substances presents a series of opportunities and challenges.

The optimal transport and logistics processes are essential in order to assure time and cost-effective recycling scheme. Transportation costs represent almost 25% of energy demand in secondary aluminium production is associated to transport and scrap preparation.

Environmental problems will be the principal driver in the metallurgical processing industrial sector in coming decades as a result of increasing recycling activities and enhanced use of secondary materials. Although aluminium recycling activities and processes cause, as any other production activity, certain impacts on the environment although they are normally much lower compared to the primary aluminium production.

*Key words: Al-Mg alloys, recycling, energy efficiency, environmental protection*

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## Introduction

The recycling of high magnesium aluminum alloys reduces waste, saves energy, conserves natural resources, lessens use of municipal landfills and provides recyclers and municipalities with considerable revenue. Used aluminum ships are an end waste that can be recycled to obtain valuable products. The compatibility of the scrap depends on which grades are chosen for construction.

Compatible grades of materials are only of use if the recycling channel can make good use of their inclusion. The aim of this project is also to suggest a method of mechano-pyrometallurgical treatments to provide a suitable way to achieve an optimum recovery efficiency of aluminum alloys.

Primary aluminium production is energy-intensive. However, process improvements have reduced the amount of energy required for production, with a decrease of over 30% from the 1950's to 1997. More than 55% of the world's primary aluminium is produced using hydro-electric power, which is considered to be clean, renewable and highly efficient. Secondary aluminium production from recovered scrap consumes only 5% of the energy required for production of primary aluminium. This makes recycling of aluminium attractive.

Aluminium is easily recycled. New scrap (from metal production) has a recycling rate of 100%, while the recycling rate for old scrap is 63%. In 1994, around 30% of the aluminium supplied to the European market originated from recycled metal. The quality of recycled aluminium is equal to that of the primary metal. Recycling of aluminium is economically attractive and a reduction of aluminium waste is thus expected in the future [1].

## Aluminum life-cycle (recycling loop)

It is well known that the re-smelting process of secondary aluminium from scrap consumes only about 5 % of the energy required for the production of primary aluminium. Therefore, the energy balance for the production of aluminium gets better if aspects of recycling are taken into consideration, too.

The aim of a recycling, with orientation towards sustainability, has to be to keep aluminium produced with high energy input in the material cycle as long as possible. Theoretically this means forever, as metals can be recycled an unlimited number of times without loosing their chemical and physical properties. Therefore, losses of the material during the life-cycle, formed of usage and recycling, have to be minimised [2].

Also, this aim has to be achieved with a minimum requirement for energy and raw materials for collection, processing and re-smelting. The recycling loop for aluminium as shown in Figure 1 can be divided in two different loops, a closed-loop and an open-loop[3].

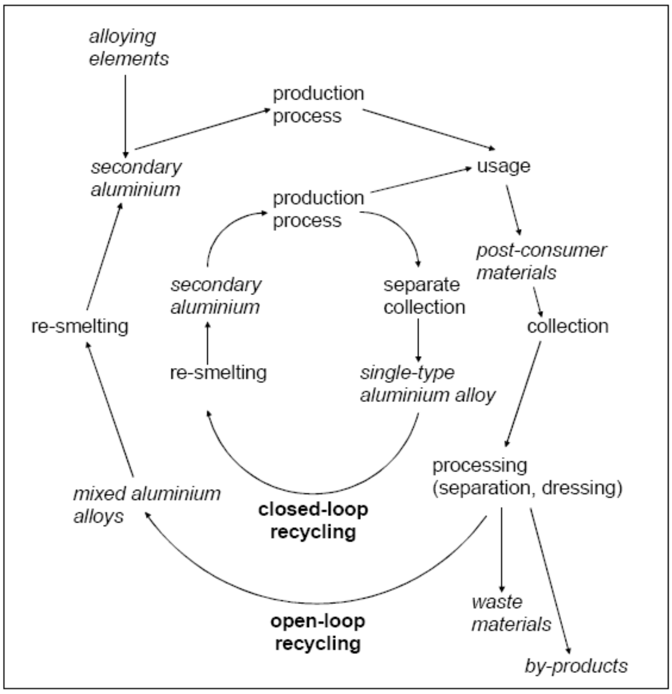



*Figure 1: Recycling loop for aluminium*

The closed-loop applies to production scrap that has only to be re-smelted and can be reused directly for the original purpose. Also, the closed-loop recycling is to be considered for aluminium applications that can easily be collected separately and therefore be reused for the same application again, e.g. aluminium rims. The open-loop applies to most of the mixed aluminium scrap recycled from usage. The collected material has to be processed before it can be re-smelted. The processing stage is often the origin for waste materials. Also, the secondary aluminium produced from the processed material can vary quality and therefore alloying elements have to be added before the secondary aluminium can be used for the production of new applications. As waste materials and by-products originate from the recycling loop and alloying elements are needed for the production of secondary aluminium, the loop is open [4].

Today, the open-loop recycling produces mainly cast alloys. High quality wrought alloys are therefore down-cycled if they are not subjected to closed-loop recycling. In this case the quality of recycling could be improved.

A major contribution towards an improvement of the recycling quality can be made by the development of a model of the secondary aluminium cycle, thus enhancing the understanding of the interactions between the different units that form this cycle [3].

For most of the industries and markets where aluminium is employed, the in-use lifetimes of goods are quite long, from several years for consumer durables and some equipment to several decades for buildings, infrastructure, and transportation vehicles [5]. There have been empirical estimates on the average lifetime of aluminium products of different industries and markets [6]. However, those estimations are uncertain given the fact that product lifetimes are widely varying and data are sparse [7].

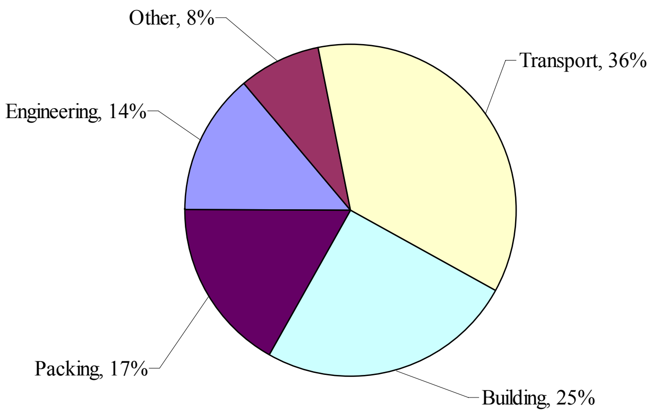



*Figure 2. Aluminium End-use Markets in Western Europe [8]*

Global aluminium recycling rates are high, approximately 90% for transport and construction applications and about 60% for beverage cans. Although recycling of flexible packaging presents a challenge, the unique barrier properties of aluminium foil are considered vital to the preservation of products (e.g. foodstuffs and medicines).

Transportation is the most important field of application of aluminium in Western Europe. In 2003, approximately 3.6 million tonnes of wrought and casting alloys were used in cars, commercial vehicles, aeroplanes, trains, ships, etc., and that figure is steadily rising. Consequently, the transport sector is also a major source of aluminium at the end of a vehicle's lifetime. The precise end of a vehicle's lifetime is, however, difficult to define. In Germany, for example, cars are used for an average period of 12 years, at the end of which they can enter the recycling loop.

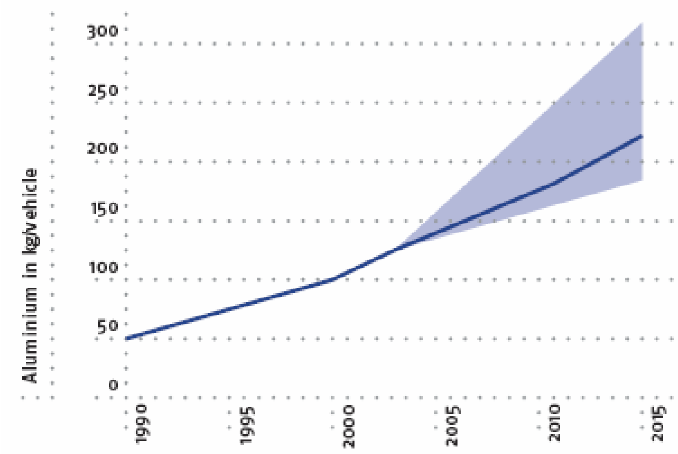
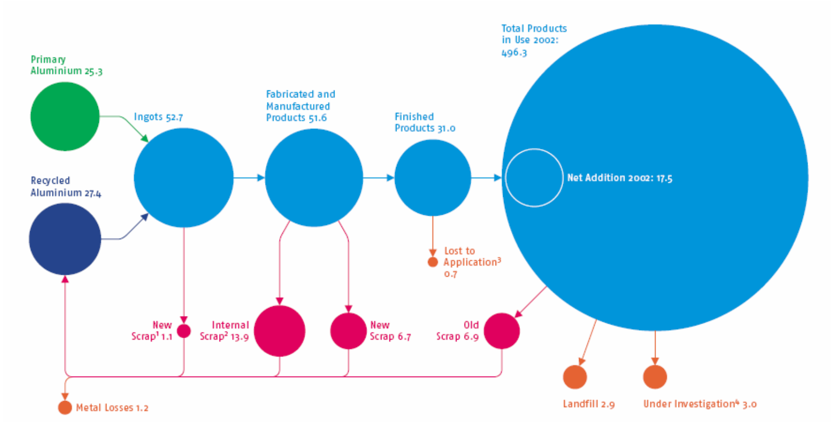



*Figure 3. Evolution of Aluminium Content in Vehicles [8]*

But their lifetime is often extended by export to less developed parts of the world, where their useful life may continue for many more years to come. Compared to other materials, aluminium scrap has very high material value, which provides sufficient economic incentive for it to be recycled. For this reason, 90% to 95% of the aluminium used in cars is collected and reused as automotive parts, or introduced into the recycling loop [8].




*Values in millions of metric tones. 1 Skimmings, scalpings, sawings 2 Not taken into account in statistics 3 Such as powder, paste and deoxidation aluminium 4 Area of current research to identify final aluminium destination (reuse, recycling or landfill)*

*Figure 4. Global Aluminium Flow, 2002 [8]*

## The model of the recycling processes for aluminium

The special properties of the metal aluminium require sophisticated processing of different types of aluminium containing materials prior to re-melting and refining. Aluminium and other materials in composites have to be liberated and afterwards separated from each other. Moreover, residues deriving from the re-melting and refining process such as salt slag or dross have to be treated. Figure 5 show the structure of the model of the recycling processes for aluminium.

First, the collection of the different aluminium containing waste materials is looked at. The most important point is how much of the theoretically available aluminium is actually collected (collection quota). The collected material is characterised based on a newly developed characterisation system where one of the main issues is the quality of the aluminium. If it is clean (which is often the case for new scrap) it is typically directly remelted.

If the aluminium occurs in combination with other materials such as e.g. iron or plastics (typical for old scrap) different processing steps are necessary in order to produce an aluminium fraction which can be re-melted. The processing sub-processes are described with their technical, economic and resource oriented data (namely the technical recycling quota). The characterisation of the processed aluminium fraction allows the identification of all melting processes applicable. If the metal fraction is clean it can either be used for metallurgical applications or it can be re-melted. If the aluminium is still combined with certain amounts of foreign materials it is typically remelted by the so-called refiners. Finally, waste materials from melting arise at the refiners as well as the remelters. These waste materials, mainly dross and salt slag, can be processed in order to recover the aluminium and/or the salt flux or they are disposed of. An important point of the model is the characterisation of the different material flows with regard to their processing- and their metallurgical properties, because the highest potential for improvements within the whole process chain of the recycling of aluminium can be found at the interface between processing and re-melting [9].

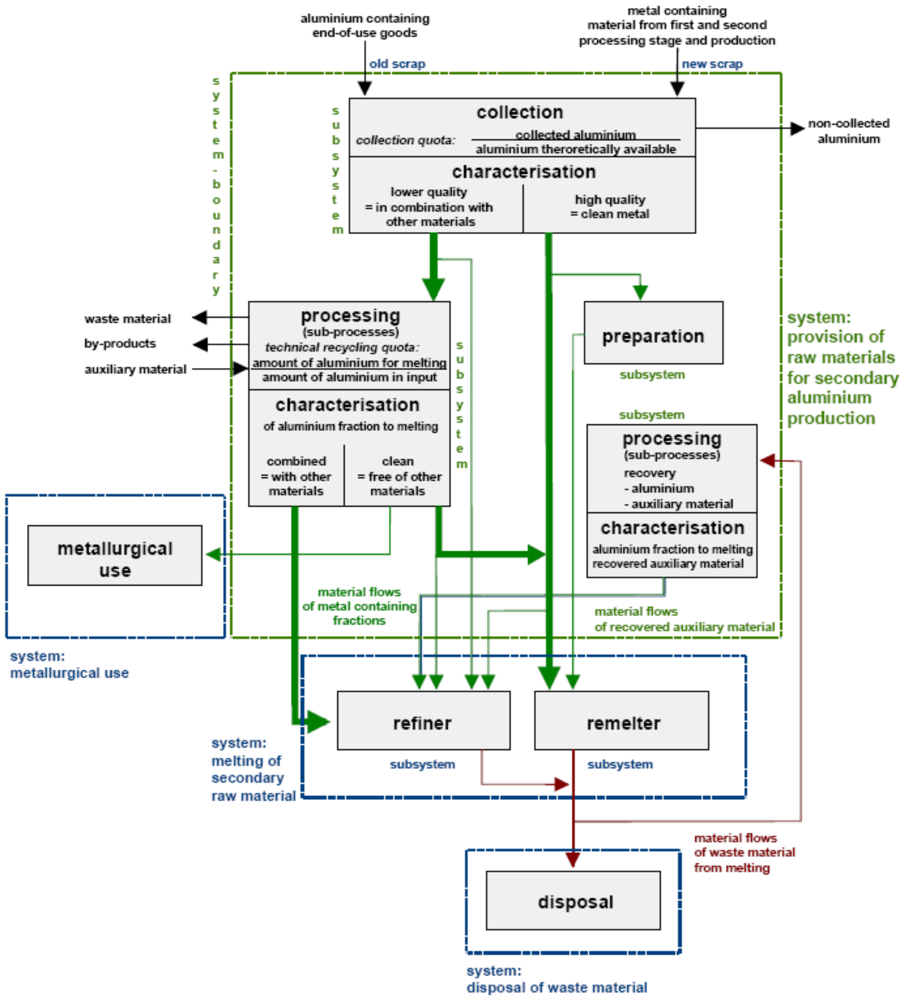



*Figure 5. Structure of the model of the recycling processes for aluminium [6].*

Litalien et al. (1997) [10], showed a recovery process of wrought alloys from mixed alloy aluminium scraps. The authors described two newly developed enabling technologies aiming to recover the full value of the aluminium from scrap containing varying amounts of contaminatinants. They agreed with Oosumi (1995) [11], that paint applied to aluminium beverage cans were the source of titanium impurity in the recycled aluminium alloys. Used beverage cans are an endless waste that can be recycled to obtain valuable products. The suggested method combined hydro-pyrometallurgical treatments and provides a suitable way to remove the printed coating using solvent extraction technique. The clean cans are then pressed to blocks prior to re-melting in a crucible furnace using sodium borate-sodium chloride mixture as a flux. The optimum recovery efficiency of aluminium alloy(s)amounts to 96.6% at 800°C. Leaching of the slag using different mineral acids produces pure valuable salts and the leaching efficiency is 99.4%. The cost price of the products is competitive to the local market price for the same primary products [12].

## Aluminium in ship building, maintenance and dismantling aspects

Aluminium is about half the weight of steel for equal strength. This gives appreciable potential for reducing fuel consumption and thus emissions during operation.

Classes of marine vessels include passenger vessels, cruise ships, fast and unconventional craft, sport and recreational vessels, merchant ships, and fishing vessels. Aluminium applications in marine vessels include hulls, structures, superstructures, upper decks, other structural and decorative applications, stairs, railings, furniture, bulkheads, and gas tanks.

In the area of ship dismantling, development of improved technologies for extraction, treatment, disposal and recycling of materials and other substances presents a series of opportunities and challenges. Some of these aspects are common to ship building and/or maintenance. R&D is required both into the technologies themselves and into the total environmental impact of introducing them. With the present profile of ship breaking nations the technologies applied should be appropriate for use in developing countries, where there is a particular need for establishment of best practices and guidelines. Development of international standards for re-use/recycling of materials would encourage a move in this direction.

The global environmental effects of ships, seen in a life cycle context, are mainly dominated by the operational phase rather than by shipyard processes such as building and dismantling. Thus, for reducing the global impact it is generally important to design and build ships for minimum environmental impact in the operational phase, e.g. by optimising the hull form to reduce fuel consumption, rather than to reduce cost and environmental impact in the building phase. However, the impact of particular shipyard processes may be significant in a local perspective. Such local impacts, and their potential longerterm global consequences, should not be disregarded [13] .

## Logistics in aluminium recycling process

Reduction of the primary resource use, pollution prevention, waste management and sustainable products policy became the focus points of modern industrial societies and environmental policy efforts. Moreover environmental problems will be the principal driver in the mining and metallurgical processing industrial sector in coming decades. Some authors even predict a decline in the mining and smelting industries in the long term as a result of increasing recycling activities and enhanced use of secondary materials.

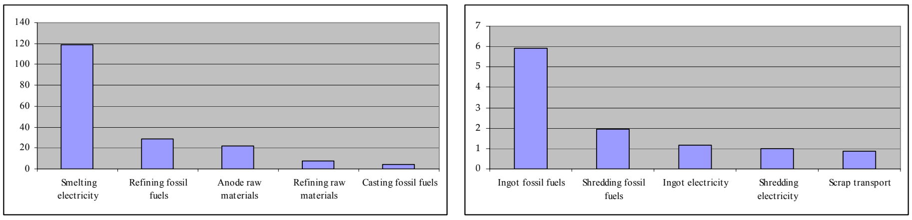
IPAI study, [14] emphasized the role of aluminium scrap transport as an important contributor to recycled ingot energy consumption. Thus, besides the efficient quality control of the input scrap it is also necessary to optimise the supply and transport activities in order to make the processes and environmental activities efficient. Nevertheless, optimised logistics processes mean not only lower transport costs but also more efficient process in terms of lower environmental impact [14]. In addition, according to some authors, collection of internal scrap (casthouse and semi-fabricator scrap) has the largest influence on the production cost [15]. Four elements have to be in place to ensure an optimum recycling of metals in general. Firstly, an effective and flexible logistics system is needed to collect and transport metal scrap from the source to the recycling plant. Secondly, disassembly facilities with state-of-the-art technology are needed to disassemble end-of-life-products into fractions that may be treated by the existing recycling industry in an environmentally friendly way. Thirdly, new developments in the recycling industry must see the light of the day in terms of increased capacity and new technology to deal with the complex mixtures of materials. Finally, the marketing of recycled materials must be improved to develop larger markets for existing materials and to open new markets for new recycled materials[16].

Efficient collection and logistics systems, and effective markets development, together with increasing costs of waste treatment and disposal, will favour the use of recycled metals in the future. In order to ensure the most effective recycling, the aluminium industry needs the highest flexibility and optimisation of processes.

## Technology

Aluminium is one of the most recyclable materials. Namely, the properties of aluminium are not affected by the recycling and reuse, thus enable that high value of the metal is maintained after reprocessing. In most European countries, the production of cast and wrought alloys made from aluminium scrap is increasing. Quantities of recycled aluminium in Europe are estimated on 2.3 million tonnes approximately (Organization of European Aluminium, OEA, 2004), although statistical data on aluminium recycling differ. European Aluminium Association states that about 32% of European aluminium demand is satisfied by recycled material (European Aluminium Association, EAA, 2003). Although the values in different studies are dependent on different conditions and local specifications, the benefits of aluminium recycling in sustainability sense are quite obvious, in general. Although aluminium recycling activities and processes cause, as any other production activity, certain impacts on the environment although they are normally much lower compared to the primary aluminium production [17].

Furthermore, the models for aluminium scrap generation were carried out (Melo, 1999; Reuter et al., 2004), as well as supply–demand analysis (Blomberg and Hellmer, 2000), calculations of environmental impacts (also studied in the context of life-cycle assessment) (von R¨openack et al., 1997; Kehlenbeck, 1996; Craighill and Powell, 1996; Huang and Ma, 2004), optimisation of recycling processes using Taguchi method (Khoei et al., 2002) and technical–economical constraints analysis for the case of aluminium recycling (Hoyle, 1995) all proved the importance of various professional and scientific fields of efficient aluminium waste management. Among the support activities of any waste management actions, the optimal transport and logistics processes are essential in order to assure time and cost-effective recycling scheme. Transportation costs represent very important part of overall recycling costs balance. A German study showed that almost 25% of energy demand in secondary aluminium production is associated to transport and scrap preparation (von R¨openack et al., 1997).




*a)* *b)*

*Fig. 6. Major energy demand contributors to aluminium ingot production in MJ: (a) primary ingot production and (b) recycled ingot production (IPAI, 2000).*

Numerous papers reported on different aspects and problems of aluminium recycling industry. For example, different authors reported on new improved recycling techniques (Xiao and Reuter, 2002; Thomas and Wirtz, 1994; Buxmann, 1994; Samuel, 2003), on optimisation of energy demand of aluminium production depending on the recycling quota (Quinkertz et al., 2001) and determination of the optimum configuration of design parameters for performance, quality and cost (Khoei et al, J Mater Process Technol 2002).

Evans & Guest in The Aluminium Decoating Handbook (Stein Atkinson Stordy Ltd http:\\www.s-a-s.co.uk) show that total metal recovery in europe is 98% with metal yield of 92% as presented in following table.

*Table 1 Efficiency of aluminium scrap melting in Europe*

| Scrap type | Metal content, % | Metal recovery, % | Metal yield, % |
|---|---|---|---|
| Building scrap | 96 | 99 | 95 |
| Transport scrap | 87 | 96 | 84 |
| Foil scrap | 73 | 96 | 70 |
| Used beverage cans | 94 | 99 | 93 |
| Engineering scrap | 86 | 96 | 83 |
| Scrap from consumer durables | 85 | 95 | 81 |
| Total old scrap | 88 | 97 | 85 |
| Total scrap | 93 | 98 | 92 |

## Environmental Regulations

Historically, the installation of emission control measures has been forced upon Industry by political and environmental pressure rather than economic or moral issues. The main instruments for driving Industry towards a cleaner environment are legal regulations, both at International and Local level. This section identifies the appropriate regulations that apply to the decoating process within these markets and they are summarised in Table 2.

*Table 2. Regulations that apply to the aluminium decoating process*

| MARKET | | U.K | GERMANY | U.S.A |
|---|---|---|---|---|
| STANDARD No | | IPR 5 / 1 | Ta Luft 3.3.8.3.1 | E.P.A 42 |
| Reference | Temp | 0 Deg C | 0 Deg C | |
| | Pressure | 1013 mb | 1013 mb | |
| | Oxygen | 11% v / v | 11% v / v | 3% v/v |
| | Water | 0 | 0 | |
| mg /Nm³ | $NO_X$ | 350 | 500 | 2240 kg/10⁶ m³ |
| | $SO_2$ | 50 | 60 kg/h av. | 9.6 kg/10⁶ m³ |
| | Volatile organic compounds | 20 | 20 | 48 kg/10⁶ m³ |
| | CO | 50 | 1000 kg/h av. | 560 kg/10⁶ m³ |
| | HCl | 10 | 50 | |
| | HF | 2 | 2 | |
| | Particulate | 20 | 20 | 16-18 kg/10⁶ m³ |
| mg /Nm³ | Cadmium | 0.1 (together) with Thallium | 0.2 (together) with Thallium | |
| | Thallium | | | |
| | Mercury | 0.1 | | |
| | Arsenic | 1 (together) Arsenic to Beryllium | 1 (together) Arsenic, Cobalt | |
| | Cobalt | | | |
| | Nickel | | 5 (together) Nickel to Beryllium | |
| | Antimony | | | |
| | Chromium | | | |
| | Copper | | | |
| | Lead | | | |
| | Manganese | | | |
| | Nickel | | | |
| | Tin | | | |
| | Vanadium | | | |
| | Beryllium | | | |
| ng /Nm³ | Dioxin TEQ | 1 * | 1 * | |

- 0.1 ng/NM³ to be aimed for.

### *Europe/UK*

Germany has traditionally led the way with environmental regulations, the document "Technical Instructions on Air Quality Control" (Ta Luft, 2002) being adopted by most European authorities as the benchmark for air pollution control. Within Europe emission limits are usually set on a process by process basis. Each process group is assigned emission limits for the appropriate pollutants based on concentration under standard reference conditions and oxygen content. The application of reference oxygen levels is to prevent attaining the required pollutant concentration purely by air dilution of the waste gas prior to discharge into the atmosphere.

The Ta Luft standard generally considered applicable to decoating is section 3.3.8.3.1 – "Facilities for the Recovery of Individual Components from Solid Substances by Combustion". Environmental control within the UK is administered by the Environmental Agency. Generally, these emission limits follow the same format and impose similar limits as Ta Luft concerning airborne pollutants but also include land and waterborne emission aspects. The note considered most applicable to the decoating process (probably due to the afterburning aspect) is IPR 5/1 – "Waste Disposal and Recycling Merchant and In-House Chemical Waste Incineration".

*USA*

Generally, the emission requirements for decoating plants within the USA is less unified than in Europe. They vary from State to State but are usually based on a permit to operate system using a maximum mass of pollutant discharged per specified timebase. EPA 42 is often used as guidance for processes involving natural gas combustion. Some authorities apply efficiency criteria to the Air Pollution Control systems themselves. From December 1999 a new standard takes effect in the USA - EPA 40 CFR Part 63 -"National Emission Standards for Hazardous Air Pollutants for Source Categories; National Emission Standards for Hazardous Air Pollutants for Secondary Aluminium production, 2000; proposed rule".

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