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Analysis of anthropogenic aluminum cycle in China

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Abstract: Anthropogenic aluminum cycle in China was analyzed by the aluminum flow diagram based on the life cycle of aluminum products. The whole anthropogenic aluminum cycle consists of four stages: alumina and aluminum production, fabrication and manufacture, use and reclamation. Based on the investigation on the 2003−2007 aluminum cycles in China, a number of changes can be found. For instance, resources self-support ratio (RSR) in alumina production dropped from 95.42% to 55.50%, while RSR in the aluminum production increased from 52.45% to 79.25%. However, RSR in the Chinese aluminum industry leveled off at 50% in the period of 2003−2007. The respective use ratios of domestic and imported aluminum scrap in the aluminum industry of 2007 were 5.38% and 9.40%. In contrast, both the net imported Al-containing resources and the lost quantity of Al-containing materials in aluminum cycle increased during the same period, as well as the net increased quantity of Al-containing materials in social stock and recycled Al-scrap. Proposals for promoting aluminum cycle were put forward. The import/export policy and reducing the loss of Al-containing materials for the aluminum industry in China in the future were discussed.

Key words: anthropogenic; aluminum cycle in China; SFA; weighted average method; average use life

1 Introduction

Element flow is composed of anthropogenic flow and natural flow. Anthropogenic flow contains three forms, including fossil fuels combustion, minerals mining and processing and biomass fuels combustion, while the natural flow contains the soil erosion, seawater splash and net primary production [1,2].

In this work, the aim is mainly focused on bauxite mining and processing, which can be called anthropogenic aluminum cycle [1]. That is because it is a human intensively industrial activity, in which primary aluminum production is an energy-intensive process. The recovery and reuse of aluminum scrap has the potential to provide an additional source for aluminum production, and the use of scrap in aluminum production can not only reduce the consumption of bauxite, but also reduce the energy input and emission output. As China's energy consumption and CO_2 emissions have increased quickly in recent years and its energy gap has been in the expansion, the recovery and reuse of aluminum scrap should be paid more attention.

From 1991 to 2007, aluminum production and consumption in China have grown sharply with the rapid development of Chinese economy by 17.25% and 16.90% respectively, which are much higher than those of the global level by 4.22% and 4.39%, as shown in Table 1 [3−5]. Aluminum production mainly depends on two kinds of resources: bauxite and scrap. As a developing country, China has been lack of scrap in recent years [6,7] so that the bauxite consumption increases more quickly than that in developed countries. Compared with the demand, bauxite is severely in shortage and can only be used for several years in the future [8]. Analysis of anthropogenic aluminum cycle is very useful in finding the recycling status of aluminum scrap in Chinese aluminum industry so that it is able to attain saving of Al-containing resources, energy consumption and reducing of waste emissions.

The studies of aluminum cycle or a certain stage in the process of aluminum cycle have already been carried out in recent years. MELO [9] used three different kinds of models to predict the amount of aluminum old scrap

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Table 1 Variation of aluminum production and consumption amount in China and globe in 1991−2007

Year	Production amount/kt		Consumption amount/kt	
	China	Globe	China	Globe
1991	962.5	19652.6	985.0	18743.4
1992	1096.0	19459.2	1328.0	18557.6
1993	1254.5	19714.6	1350.0	18133.6
1994	1498.4	19111.8	1537.0	19715.3
1995	1869.7	19663.6	1685.0	20551.7
1996	1900.7	20846.3	1750.0	20683.8
1997	2178.6	21798.1	2115.0	21869.8
1998	2435.3	22653.9	2425.4	21889.3
1999	2808.9	23707.1	2925.9	23355.5
2000	2989.2	24418.1	3532.7	25059.1
2001	3575.8	24436.0	3545.4	23721.5
2002	4511.1	26076.0	4152.0	25372.3
2003	5962.0	28000.6	5177.6	27606.5
2004	6688.8	29921.7	6190.9	29960.6
2005	7806.0	32020.8	7118.6	31709.3
2006	9264.0	33965.1	8380.0	33994.6
2007	12284.0	38087.3	11979.0	37246.4
Increasing rate	17.25%	4.22%	16.90%	4.39%

in the waste management stage in Germany. BOIN and BERTRAM [10] carried out mass balance analysis in the aluminum recycling industry for the EU-15 in 2002. MARTCHEK [11] used a simplified model to analyze the global aluminum cycle in 2003. PLUNKERT [12] adopted aluminum flow framework to analyze the aluminum cycle in the United States in 2000. HATAYAMA et al [13] calculated the output of aluminum old scrap produced from different sectors. DAHLSTRÖM and EKINS [14] analyzed aluminum flow in the United Kingdom in 2001 combining substance flow analysis and value chain analysis together. In China, CHEN et al [15] used aluminum flow diagram to analyze aluminum cycle of China in 2005 and they explored the production, consumption, import and export, losses and changes of stocks of aluminum in China for 2001, 2004 and 2007 [16]. However, most of these studies were snapshots of bauxite mining and processing in one year period. They did not consider how long the use life of aluminum products is and primarily care about aluminum flows in one year period. In fact, it is better to combine the analysis of anthropogenic aluminum cycle with the average life span of aluminum products life cycle. Then, it can show us the whole picture of anthropogenic aluminum cycle, which is useful in knowing the fundamental characteristics of aluminum flow, e.g. the influence of aluminum products output on the availability of secondary resources for aluminum industry.

This work is based on the theory of metal's industrial metabolism [17,18], and combined the analysis of aluminum cycle with the average use life span of aluminum products. Firstly, we give the anthropogenic aluminum flow diagram based on the aluminum products life cycle; secondly, the average use life of aluminum products life cycle was analyzed by the weighted average method; then substance flow analysis with time factor of the products life cycle [7,19,20] was adopted to analyze anthropogenic aluminum cycle in China in 2007; next, aluminum flow indices of Chinese aluminum industry during the period of 2003−2007 were calculated; last, but certainly not least, proposals for future development of Chinese aluminum industry were discussed.

2 Methodology

2.1 Anthropogenic aluminum flow diagram based on life cycle of aluminum products

The entire anthropogenic aluminum cycle comprises four stages, as shown in Fig. 1 [7,19−23].

Some explanations for the four stages are as follows [l3−15].

1) Production: Bauxite mining/milling, the production of alumina and aluminum, has been treated as a separate process, and is shown at stage I. The dissipating amount of Al-containing materials during this stage contains tailing, red sludge and slag.

2) Fabrication & manufacture: The stage II is the fabrication and manufacture stage of the aluminum products. Aluminum flows at this stage include the fabrication of aluminum semis and aluminum alloy semis, and the manufacture of intermediate commodities and finished products.

3) Use: Aluminum products leave the manufacture stage in the form of finished products or being embedded into assembled products (e.g. automobiles). When the aluminum products are produced, they are widely used in national economy, such as constructions and vehicles.

4) Waste management: The retrieve of obsolete aluminum products is the fourth stage in aluminum cycle. Some of obsolete aluminum products are retrieved after their life cycle $\Delta\tau$, while some are permanently stored in terrestrial establishments and constructions; otherwise, they will be dissipated into environment during their life cycle. Aluminum products usually enter their use period after being produced, while the scraps are often recycled in the same year as they are retrieved from obsolete aluminum products. Therefore, the average life span of aluminum products life cycle usually depends on both the distribution of different use