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Carbon Footprint of Monosodium Glutamate Production in China

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Monosodium glutamate (MSG) production has been attracting environmental concerns due to its high energy consumption and high pollutant discharge, especially to water and the air. The water footprint of MSG has been investigated in previous studies; however, the carbon emissions have not been evaluated. This study conducted a carbon footprint analysis on monosodium glutamate production, to identify the critical material and stage that contribute the most to the carbon footprint during MSG production. The results indicated that the carbon footprint of producing 1 t of MSG is 3.14×10^3 $kgCO_2eq$, and 32.92 % of which is from the extraction and refinement process. Indirect emissions from raw materials used in MSG production, such as caustic soda liquid and concentrated sulfuric acid, and on-site emissions from the prodsteam production are major carbon footprint contributors. In addition, the glutamate fermentation stage accounts for 23.35 % of the total carbon footprint of MSG production due to the use of steam and liquid ammonia. In terms of the hotspot of carbon footprint in MSG production, it is identified that the steam used is the largest contributor, accounting for 34.90 % of the total carbon footprint in MSG production, followed by coal (16.47 %). Based on the research results, several cleaner production suggestions, such as greener raw materials utilization, green supply chain construction, and industrial symbiosis network establishment are proposed to further reduce the overall carbon footprint of MSG production.

1. Introduction

Monosodium glutamate (MSG), a sodium salt of glutamate, is the most exported and consumed food flavour enhancer worldwide. China is also the biggest MSG producer and exporter, taking approximately 76 % of the world's total MSG production capacity. According to the data released by China Biological Fermentation Industry Association, MSG production in China has been on the rise in recent years (CBFIA, 2021; 2023). The specific production is shown in Figure 1. The production methods of MSG include extraction from natural materials (such as soybean, and beet), chemical synthesis, enzymatic catalysis, and fermentation (Ault and Addison, 2004). Fermentation has become the most important process because of its low cost, wide range of raw materials and minimal environmental impact (Zhang et al., 2012). However, the fermentation-based MSG production method is water and energy intensive and also generates a large amount of wastewater with high levels of chemical oxygen demand (COD), ammonia nitrogen and sulfate (Xue et al., 2008).
Researchers have conducted several studies investigating the production of different kinds of monosodium glutamate products in recent years. Dong et al. (2018) reviewed the development and cleaner production progress of MSG industries in China from 2005 to 2015. The sludge disposal of MSG wastewater treatment and air pollution were still the major challenges in MSG industries. Yang et al. (2020) studied the production of monosodium glutamate in China and concluded that improving energy use efficiency (and/or using cleaner

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energy) and modifying the production process to maximize material use efficiency are the two potential directions to further improve the environmental performance of MSG production. Nakamura et al. (2021) Compared the environmental performance of two production models for MSG produced using tapioca starch and non-biomass. It was concluded that the latter process had less impact on the environment and human health than the non-biomass process, but there were still some environmental problems to be solved. Ding et al. (2022) focused on four typical scenarios of monosodium glutamate production in China and indicated that with the improvement of cleaner production level, the environmental impact of MSG production decreased significantly.

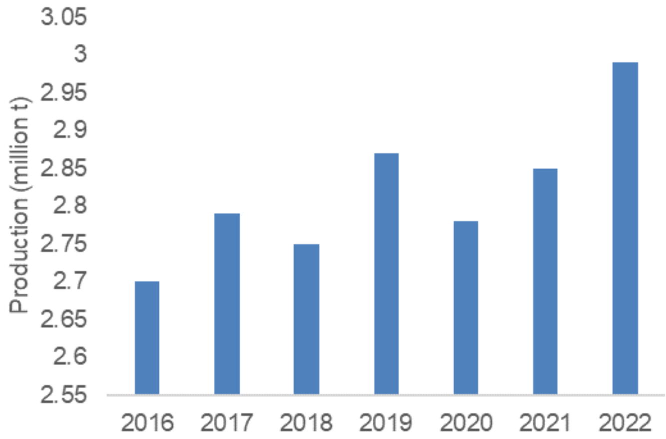

Figure 1: The MSG production lever of China (2016-2022)

Carbon footprint is one of the typical representative indexes based on the life cycle assessment method for assessing greenhouse gas emission for a production system (ISO, 2013). This effective method has been used to evaluate the greenhouse gas emissions of industrial products during the full life cycle such as cement (Ping et al., 2020), vegeburger (Wróbel-Jędrzejewska et al., 2021), steel (Qi et al. 2018), textile (Chen et al., 2023), sugar (Yuguda et al., 2020) and milk (Ledgard et al., 2020). Such a method can identify the greenhouse gas emissions hotpots of the production processes and provide data to support future energy conservation (Finnveden et al., 2009) and emission reduction for industrial enterprises (KlöPffer, 2006).
However, there are only a few carbon footprint studies conducted focusing on the amino acid products by fermentation, let alone MSG products. In order to fill the research gap, this study analyzed the carbon footprint of MSG production in China, which can serve as a benchmark for future improvements. The data is obtained from representative MSG production enterprises in China. By conducting the carbon footprint analysis of MSG production, this study attempts to gain a deeper understanding of the hotspots of greenhouse gas emissions at each stage of MSG production and provide scientific guidance for reducing greenhouse gas emissions decision-making to promote low carbon development in the MSG industries.

2. Materials and method

In this study, the IPCC method (IPCC, 2013) is used for the carbon footprint calculation based on the Life Cycle Inventory Analysis (LCIA), and the eBalance software (Yang et al., 2018) is used for the carbon footprint analysis. The carbon footprint of MSG production in the study area is measured from "cradle to gate" according to the requirements of the Life Cycle Assessment method. The carbon footprint calculation is as follows.

$$\mathrm{CF} = \sum_{i=1}^{n} \mathrm{V_i} \times \mathrm{F_i} \quad (1)$$

Where CF is the carbon footprint of MSG production ($kgCO_{2eq}$), $\mathrm{V_i}$ notes the first i consumption/output of a resource or energy, $\mathrm{F_i}$ notes the emission factors of the first i resource or energy.

2.1 Goal, scope, and functional unit

A cradle-to-gate approach is adopted to determine the system boundary (Figure 2), in which all the processes of raw materials and energy production, transport of raw materials, on-site emissions, and waste disposal associated with MSG production are included. The functional unit in this article is 1 t MSG production, all the raw material inputs, products, and energy consumption are based on this functional unit.

2.2 System description of MSG production

In line with the life cycle assessment framework, the system boundary in this study was from starch milk production from maize to MSG products (cradle to gate) (Figure 2). The production of MSG usually uses maize as raw material. Maize is crushed and ground to produce starch that produces glucose under the action of glucoamylase and cellulase. Glucose is then fermented and extracted to produce sodium glutamate, and finally produces sodium glutamate products by decolorization and crystallization. Besides the main product sodium glutamate, there are also by-products such as germ, feed protein powder, sugar residue, organic fertilizer and bacterial protein in the production process of MSG. The allocation method of main products and by-products is based on the economic value of the (by) products.

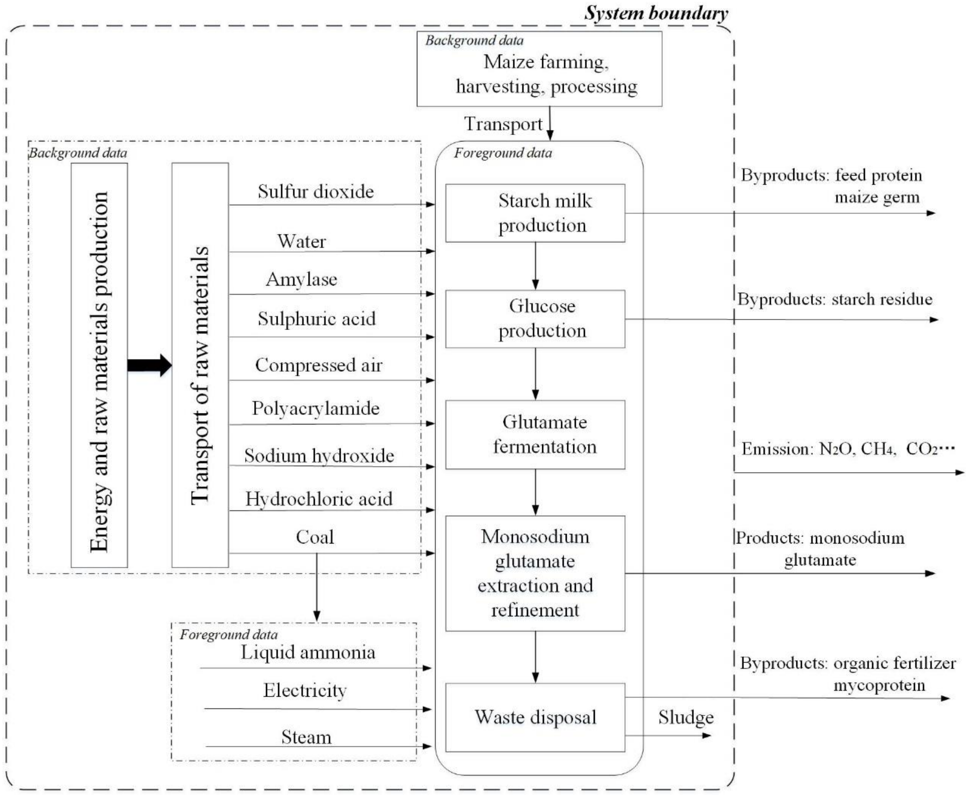

Figure 2: System boundary of the MSG production system

2.3 Life cycle inventories

The life cycle inventory results are listed in Table 1. All the raw materials and energy consumption (e.g., maize, sulfur acid, ammonia, water, electricity, and steam), transportation of raw materials, on-site emissions (e.g., wastewater, carbon dioxide and volatile organic compounds), and waste disposal processes are calculated based on the functional unit. As for the byproducts such as fertilizers and ammonium sulfate produced in MSG production, the economic-value distribution method is used to allocate the material and resource consumption. The inventory data in this article, such as the consumption of resources and energy in Table 1, is based on field survey data from one of the top three MSG manufacturers in China. The emission factors of resources and substances consumed (e.g., hydrochloric acid, sulfur acid, and liquid ammonia, electricity, steam, etc.) are obtained from the Chinese reference life cycle database (CLCD), which is China's localized life cycle basic database, covers more than 400 materials (Li et al., 2021). The background inventory data of maize farming, harvesting, and processing is obtained from the Ecoinvent database (Steubing et al., 2022）.

Table 1: The resource and energy consumption of 1t MSG production

Process unit	Parameters	Unit	Value
Starch milk production	maize	t	2.40
	water	t	4.61
	electricity	kWh	254
	steam	t	1.34
	sulfur dioxide	kg	4.43
Glucose production	starch milk	t	1.70
	water	t	0.371
	electricity	kWh	18.4
	steam	t	56.6
Glutamate fermentation	glucose	t	1.62
	water	t	2.03
	electricity	kWh	0.0241
	steam	t	2.33
	compressed air	m^3	2.02
	liguid ammonia	kg	314
	sodium hydroxide	kg	29.2
MSG extraction and refinement	fermentation broth	t	0.877
	water	t	29.2
	electricity	kWh	146
	steam	t	3.19
	concentrated sulfuric acid	kg	621
	sodium hydroxide	kg	219
	liquid ammonia	kg	87.7
	polyethylene	kg	11.7
	hydrochloric acid	kg	1.28
	flocculants	kg	2.19
Tail liquid utilization	tail liquid	t	7.31
	electricity	kWh	143
	steam	t	0.768
	coal	t	0.329

3. Results analysis

The results of the carbon footprint assessment based on the LCIA are presented in Table 2. The carbon footprint of 1 t MSG produced from maize is 3.14×10^3 $kgCO_{2eq}$. When comparing the carbon footprint of different stages, the MSG extraction and refinement process has the most carbon footprint of 1.03×10^3 kg CO_{2eq} per t MSG and accounts for 32.92 % of the life cycle carbon footprint of MSG production. Glutamate fermentation broth production is the second largest contributing process to the carbon footprint of MSG production. The glutamate fermentation process has a carbon footprint of 733 $kgCO_{2eq}$ per t MSG and accounts for 23.35 % of the life cycle carbon footprint of MSG production. The carbon footprint of the starch milk production process and the tail liquid utilization are 635 $kgCO_{2eq}$ per t and 632 $kgCO_{2eq}$ per t, respectively. In the end, the Glucose production process has the least contribution of 106 $kgCO_{2eq}$ per t to the carbon footprint of MSG production.

Table 2: The carbon footprint of 1 t MSG production($kgCO_2$-eq).

Life cycle stage	Value
Starch milk production	635
Glucose production	106
Glutamate fermentation	733
MSG extraction and refinement	1.03×10^3
Tail liquid utilization	632
Total	3.14×10^3

The main contributors to the carbon footprint of MSG production are also analysed and presented in Figure 3. Energy consumption, including steam, coal, and electricity, is the largest contributor to the carbon footprint of MSG production, taking 36.08 %, 16.47 %, and 8.53 % of the carbon footprint of MSG production. The main reason is that a lot of steam is used in the starch milk production process, glutamate fermentation process, and MSG extraction and refinement process.

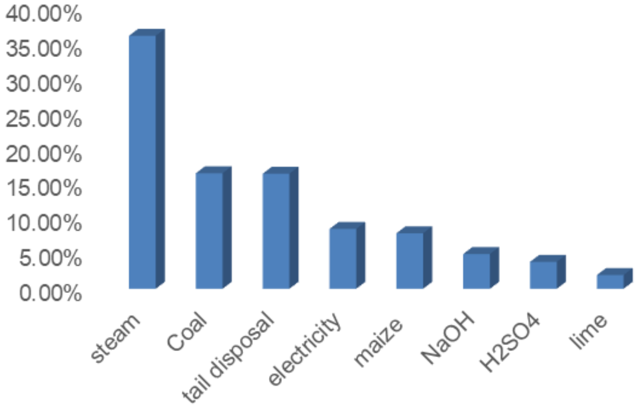

Figure 3: The main contributors to the carbon footprint of MSG production

4. Conclusions

With the increasing requirements of low-carbon transformation, how to further improve the carbon footprint performance of the MSG industry still requires investigation. In this study, the carbon footprint analysis based on the Life cycle assessment is used to evaluate the carbon footprint of MSG production based on the fermentation method in China.

Based on the analysis of the overall carbon footprint and the main contributors of MSG production in China, the carbon footprint of producing 1 t MSG is 3.14×10^3 $kgCO_{2eq}$. The carbon footprint of the starch milk production process, glucose production process, glutamate fermentation process, MSG extraction and refinement process, and tail liquid utilization process are the 635 $kgCO_{2eq}$, 106 $kgCO_{2eq}$, 733 $kgCO_{2eq}$, 1.03×10^3 $kgCO_{2eq}$, and 632 $kgCO_{2eq}$, respectively. The main source of carbon footprint is energy consumption such as steam, coal, and electricity in MSG production. The largest hotspot of carbon footprint in MSG production in China is MSG extraction and refinement process due to energy consumption such as electricity and steam, followed by glutamate fermentation process. Based on the results, it is suggested that cleaner energy and more energy-efficient MSG extraction and refinement process should be used to reduce the carbon footprint of MSG.

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