Life Cycle Assessment of a Coke Cleaning Agent

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The life cycle assessment of the coke cleaning agent developed by a university-enterprise cooperation project was conducted. This cleaning agent has the characteristics of phosphorus-free, environmentally friendly, and broad market prospects. The life cycle assessment of the established model showed that the GWP of producing 1kg of coke cleaning agent is 1.19 kg CO_2 eq, PED is 13.17 MJ, WU is 186.74 kg, AP is 3.63E-03 kg SO_2 eq, ADP is 7.75E-05 kg antimony eq, EP is 1.30E-03 kg PO43-eq, RI is 1.16E-03 kg PM2.5 eq, ODP is 4.63E-06 kg CFC-11 eq, and POFP is 1.85E-03 kg NMVOC eq .The uncertainty of the results is between 4.20% and 24.05%. The carbon footprint (GWP) analysis showed that the production process of isotridecanol polyoxyethylene ether, isopropanol, fatty alcohol polyoxyethylene ether M and isodecanol polyoxyethylene ether contributed significantly. The average sensitivity analysis showed that the most influential processes were sodium lauryl amphoacetate, isopropanol, and tripropylene glycol methyl ether.

Keywords: Life Cycle Assessment; Descaling Agent; Carbon Footprint; Coke; Production

Introduction

As an important aspect of modern household, the hygiene level of the kitchen has been paid more and more attention by people [1]. During the cooking process, the edible oil and the grease in the food are vaporized under high temperature heating conditions for a long time, and then condense and adhere to the surface of the range hood, gas stove and other objects [2]. Then the dirt adsorbs the dust in the air to form the sticky kitchen dirt. These greasy dirt is often accompanied by odors and is difficult to be cleaned [3], [4]. As people have higher requirements for the removal of oil stains, cleaning agents are often needed to effectively remove them [5],[6].

Although the formula of ordinary cleaners is stable, they are not targeted and professional, and there are problems such as incomplete cleaning of dirt and environmental pollution [7]. At present, the main grease cleaning agents on the market are mostly formulated with high organic solvent content and high alkali, which contain harmful solvents and damage the surface of objects [8], [9]. In this paper, the life cycle of the production process of coke cleaning agent was studied. This product is a water-

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based cleaning agent and has the characteristics of safety, high efficiency, low corrosion and environmental protection.

Materials and Methods

Goal and Scope Definition

The research object of this study is coke cleaning agent which is a water-based environment-friendly cleaning agent. In its formula, a variety of surfactants, organic solvents, and auxiliary agents are used. It has strong ability to remove tar scale and carbon deposits on the surface of kitchen utensils. It will not damage the surface of the utensils, and will maintain the original luster. The cleaning agent is also phosphorus-free with a very broad market prospect [10]. The product is a suspension, and the functional unit is 1 kg product. Time representation is 2021, and geographical representation is China

The system boundary of this study is from the cradle to the gate (out of factory), and the actual processes mainly include the production processes of sodium lauryl amphoacetate, isotridecanol polyoxyethylene ether, fatty alcohol polyoxyethylene ether M, isomeric ten alcohol polyoxyethylene ether, isopropanol, tripropylene glycol methyl ether, triethylene glycol butyl ether and disodium EDTA. Background processes include electrical grids, transportation and chemicals.

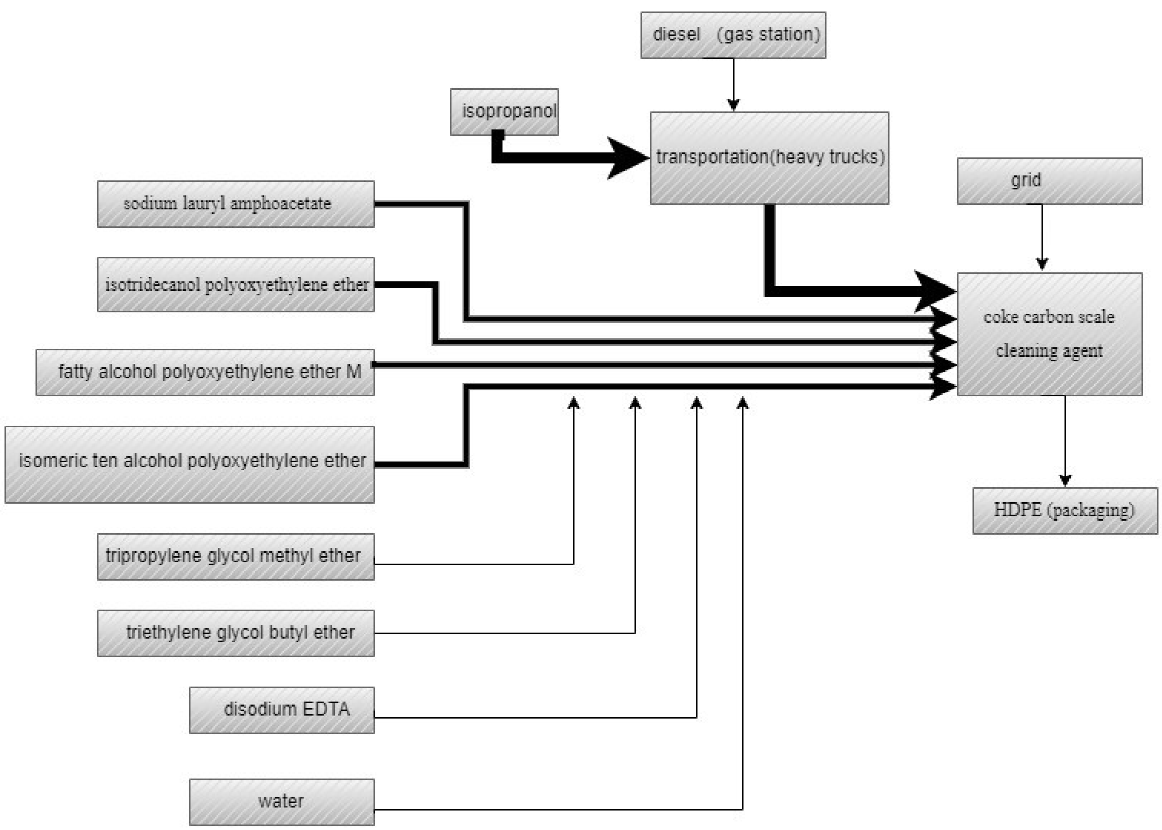

Figure 1. System boundary of the coke cleaning agent

Selection Principle

The selection rule is based on the weight ratio of each raw material input to the product weight or the total process input. The specific rules are as follows:

(1) When the weight of ordinary materials is less than 1% of the weight of the product, and the weight of materials containing rare or high-purity components is less than 0.1% of the weight of the product, the upstream production data of the material can be ignored. The total weight of ignored materials does not exceed 5%.

(2) For low-value wastes as raw materials, such as fly ash, slag, straw, household waste, etc., the upstream production data can be ignored.

(3) In most cases, production equipment, workshops and living facilities can be ignored.

(4) Known emission data within the scope of the selected types of environmental impact should not be ignored.

Types of Environmental Impact

Table 1. Types of environmental impact indicators

Environmental impact indicator	Unit	Main list substance
Climate change	kg CO_2 eq.	CO_2, CH_4, N_2O…
Primary energy consumption	MJ	Hard coal, lignite, natural gas...
Abiotic resource consumption	kg antimony eq.	Iron, manganese, copper…
Water consumption	kg	Fresh water, surface water, groundwater…
Acidification	kg SO_2 eq.	SO_2, NOx, NH_3…
Eutrophication	kg PO_4^{3-} eq.	NH_{-3}，NH_4-N，COD…
Inhalable inorganic substances	kg PM2.5 eq.	CO, PM_{10}, $PM_{2.5}$…
Ozone depletion	kg CFC-11 eq.	CCl_4, $C_2H_3Cl_3$, CH_3Br…
Photochemical ozone synthesis	kg NMVOC eq.	C_2H_6, C_2H_4…

Note: eq is the abbreviation of equivalent.

Data Quality Requirements

Data quality represents the difference between the target representativeness and the actual representativeness of the data of the LCA study. The China Life Cycle Basic Database (CLCD) method was adopted as the data quality assessment method. The CLCD method was used to evaluate the consumption and emission inventory data in the model from four aspects: ① inventory data sources and algorithms, ② time representativeness, ③ geographic representativeness, ④ technical representativeness. Using the method, the consumption of the background database was correlated and the uncertainty of its match with the upstream background process was assessed. After completing the inventory uncertainty assessment, the analytical formula method was used to calculate the uncertainty transfer and accumulation, and the uncertainty of the LCA results were obtained [11].

Software and Database

In this study, the eFootprint software system was used to establish the life cycle model of the coke cleaning agent, and the LCA results were calculated. The eFootprint software system is online LCA analysis software developed by Yike Environmental Technology Co., Ltd. It supports the analysis of the whole life cycle process, and has built-in CLCD database, EU ELCD database and Swiss Ecoinvent database [12].

The CLCD used in the research process is an industry average database developed by Yike and based on the core model of China's basic industrial system life cycle. The CLCD database includes inventory datasets of major domestic energy, transportation, and basic raw materials. The background data sources used in this study are shown in Table 2:

Table 2. Coke cleaning agent [production] background data source

List name	Dataset name	Name database
Isotridecanol polyoxyethylene ether	Fatty alcohol polyoxyethylene ether sodium sulfate	LCAcontest4-39@ike-global.com 0.0
Fatty alcohol polyoxyethylene ether M	Fatty alcohol polyoxyethylene ether sodium sulfate	LCAcontest4-39@ike-global.com 0.0
Isomerized ten alcohol polyoxyethylene ether	Fatty alcohol polyoxyethylene ether sodium sulfate	LCAcontest4-39@ike-global.com 0.0
Isopropyl alcohol	Isopropyl alcohol	CLCD-China-ECER 0.8
Tripropylene glycol methyl ether	Dipropylene glycol monomethyl ether	Ecoinvent 3.1
Triethylene glycol butyl ether	Ethylene glycol dimethyl ether	Ecoinvent 3.1
Disodium EDTA, dihydrate	EDTA, ethylenediaminetetraacetic acid	Ecoinvent 3.1
Water	Tap water (industrial use)	CLCD-China-ECER 0.8
Electricity	East China Power Grid (to users)	CLCD-China-ECER 0.8

Data Collection

Coke cleaning agent [Production]

(1) Basic information of the process
Process Name: coke cleaning agent [production]
Process Boundaries: from cradle to gate
(2) Data representation
Main data sources: business surveys and literature[13][14]
Company: Jiangsu Biotechnology Co., Ltd.
Place of production: China
Base year: 2021
Process equipment: reactor, vacuum pump, condenser, heat exchanger
Main raw materials: organic raw materials
Main energy consumption: electricity
Production scale: 2000t/y
(3) Technical supplementary description:

The process simulation was carried out to obtain material balance and energy consumption balance for the production process. Figure 2 shows the flow chart. The water was injected into the reactor 1 through the pump 1, and then the main raw materials of the coke cleaning agent were sequentially added under the condition of 40°C under stirring condition. The raw materials include sodium lauryl amphoacetate, isotridecanol polyoxyethylene ether, fatty alcohol polyoxyethylene ether M, and isomeric ten alcohol polyoxyethylene ether. After being stirred for 20 minutes, disodium EDTA powder was added, and the mixture was further stirred for 10 minutes.

The mixed solution was pumped through the heat exchanger by the pump 2 to lower the temperature to 20°C. After the temperature was lowered to 20°C, the mixture entered the reactor 2, in which the organic solvents of isopropyl alcohol, tripropylene glycol methyl ether, and triethylene glycol butyl ether were added. The mixture was stirred for 20 minutes to form a homogeneous solution, after which it can be taken out and canned through a packaging machine.

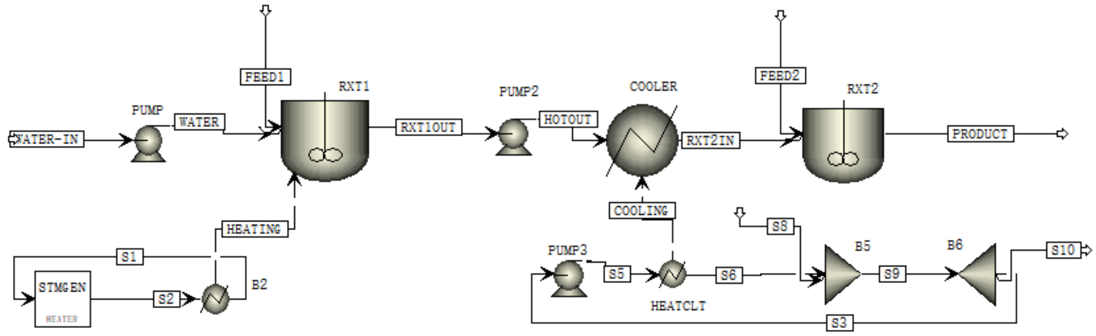

Figure 2. Coke cleaning agent production process

Sodium lauryl amphoacetate［Production］
(1) Basic information of the process
Process Name: Sodium lauryl amphoacetate［Production］
Process Boundaries: From cradle to gate
(2) Data representation
Main data sources: business surveys and literature[15]
Place of production: China
Base year: 2020
Process equipment: reactor, vacuum pump, heat exchanger
Main raw materials: organic raw materials
Main energy consumption: electricity
Production scale: 2000 t/y

Results and Discussion

Life Cycle Impact Analysis

LCA Results

The LCA results of 1kg coke cleaning agent were calculated by using the eFootprint software, and the calculated environmental indicators were climate change (GWP), primary energy consumption (PED), water consumption (WU), acidification (AP), abiotic Resource consumption potential value (ADP), eutrophication potential value (EP), inhalable inorganic matter (RI), ozone depletion (ODP), and photochemical ozone synthesis (POFP). The results were shown in Table 3.

Table 3. **LCA results of coke cleaning agent (1kg)**

Environmental impact indicator	Unit	LCA result
GWP	kg CO_2 eq	1.19
PED	MJ	13.17
WU	kg	186.74
AP	kg SO_2 eq	3.63E-03
ADP	kg antimony eq	7.75E-05
EP	kg PO_4^{3-}eq	1.30E-03
RI	kg PM2.5 eq	1.16E-03
ODP	kg CFC-11 eq	4.62E-06
POFP	kg NMVOC eq	1.85E-03

Process Cumulative Contribution Analysis

The cumulative contribution of a process is the cumulative value of the direct contribution of the process and the contributions of all upstream processes (*i.e.*, contributed by the consumption of raw materials). Since the process usually contains multiple items of inventory data, the process contribution analysis is actually the accumulation of the sensitivity of multiple items of inventory data.

Table 4. LCA cumulative contribution results of coke cleaning agent

Process Name	GWP	PED	WU	AP	ADP
Coke cleaning agent [Production]	1.19	13.2	187	3.63E-03	7.75E-05
Electricity	4.73E-02	6.20E-01	1.85E-01	2.67E-04	5.58E-07
Sodium lauryl amphoacetate	0.146	2.58	176	5.02E-04	1.21E-05
Isotridecanol polyoxyethylene ether	0.235	0.12	3.59E-02	3.56E-04	1.08E-07
Fatty alcohol polyoxyethylene ether M	0.147	7.52E-02	2.24E-02	2.22E-04	6.77E-08
Isomerized ten alcohol polyoxyethylene ether	0.147	7.52E-02	2.24E-02	2.22E-04	6.77E-08
Isopropyl alcohol	0.213	3.50	9.83	6.98E-04	1.75E-05
Tripropylene glycol methyl ether	0.144	3.25	1.74E-03	7.80E-04	2.23E-05
Triethylene glycol butyl ether	6.76E-02	2.10	3.42E-04	3.62E-04	1.82E-05
EDTA, dihydrate	4.23E-02	0.843	3.90E-04	2.17E-04	6.54E-06
Water	1.28E-04	1.68E-03	0.683	6.71E-07	1.66E-09

Table 4. LCA cumulative contribution results of coke cleaning agent (continued)

Process Name	EP	RI	ODP	POFP
Coke cleaning agent [Production]	1.30E-03	1.16E-03	4.62E-06	1.85E-03
Electricity	1.66E-05	7.97E-05	1.21E-10	1.97E-05
Sodium lauryl amphoacetate	1.60E-04	1.27E-04	2.80E-11	6.86E-05
Isotridecanol polyoxyethylene ether	1.48E-04	6.72E-05	2.02E-06	2.56E-04
Fatty alcohol polyoxyethylene ether M	9.28E-05	4.20E-05	1.26E-06	1.60E-04
Isomerized ten alcohol polyoxyethylene ether	9.28E-05	4.20E-05	1.26E-06	1.60E-04
Isopropyl alcohol	1.74E-04	5.55E-04	1.50E-08	3.18E-04
Tripropylene glycol methyl ether	3.82E-04	1.52E-04	5.36E-08	5.15E-04
Triethylene glycol butyl ether	1.18E-04	5.61E-05	5.96E-09	2.31E-04
EDTA, dihydrate	1.19E-04	3.75E-05	9.08E-09	1.20E-04
Water	6.90E-08	2.06E-07	2.80E-13	5.11E-08

The obtained data was summarized and plotted to analyze the LCA results (Figures 3-11):

(1) For the climate change indicator (GWP), the four processes that contributed the most were the production of isotridecanol polyoxyethylene ether production (0.235 kg CO_2 eq),

isopropanol (0.213 kg CO_2 eq), fatty alcohol polyoxyethylene ether M(0.147 kg CO_2 eq) and isomerized ten alcohol polyoxyethylene ether (0.147 kg CO_2 eq).

(2) Primary energy consumption (PED): The three processes that contributed the most were the production of isopropanol (3.50MJ), tripropylene glycol methyl ether (3.25MJ), and sodium lauryl amphoacetate (2.58MJ).

(3) Water resource consumption (WU): The three processes that contributed the most were the production of sodium lauryl amphoacetate (176kg), isopropanol (9.83kg), and water (0.683kg).

(4) Acidification (AP): The three processes that contributed the most were the production of tripropylene glycol methyl ether (7.80E-04 kg SO_2 eq), isopropanol (6.98E-04 kg SO_2 eq), and sodium lauryl amphoacetate(5.02E-04 kg SO2 eq).

(5) Abiotic resource consumption potential (ADP): The three processes that contributed the most were the production of tripropylene glycol methyl ether (2.23E-05 kg antimony eq), triethylene glycol butyl ether (1.82E-05 kg antimony eq), and isopropanol.(1.75E-05 kg antimony eq).

(6) Eutrophication potential (EP): The three processes that contributed the most were the production of tripropylene glycol methyl ether (3.82E-04 kg PO_4^{3-}eq), isopropanol (1.74E-04 kg PO_4^{3-}eq) and sodium lauryl amphoacetate (1.60E-04 kg PO_4^{3-}eq).

(7) Inhalable inorganics (RI): The three processes that contributed the most were the production of isopropanol (5.55E-04 kg PM2.5eq), tripropylene glycol methyl ether (1.52E-04 kg PM2.5eq) and sodium lauryl amphoacetate (1.27E-04 kg PM2.5eq).

(8) Ozone depletion (ODP): The three processes with the largest contribution were the production of isotridecanol polyoxyethylene ether (2.02E-06 kg CFC-11eq), fatty alcohol polyoxyethylene ether M (1.26E-06 kg CFC-11eq) and isomeric ten alcohol polyoxyethylene ether (1.26E-06 kg CFC-11eq).

(9) Photochemical ozone synthesis (POFP): The three processes that contributed the most were the production of tripropylene glycol methyl ether (5.15E-4 kg NMVOC eq), isopropanol (3.18E-04 kg NMVOC eq) and isotridecanol polyoxyethylene ether (2.56E-04 kg NMVOC eq).

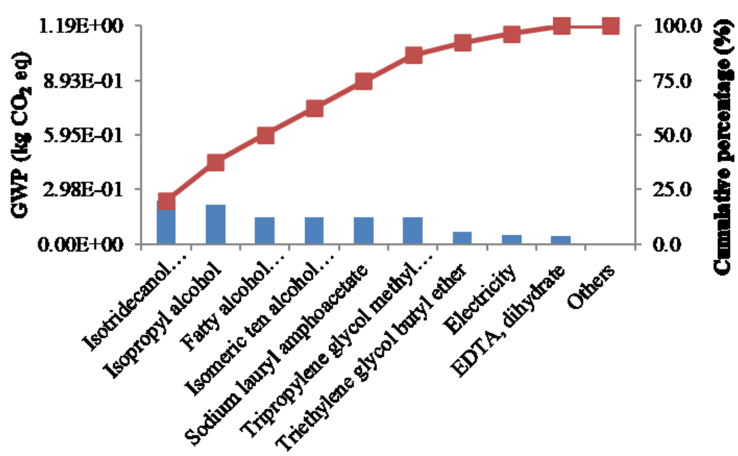

Figure 3. Climate change (GWP) results of coke cleaning agent

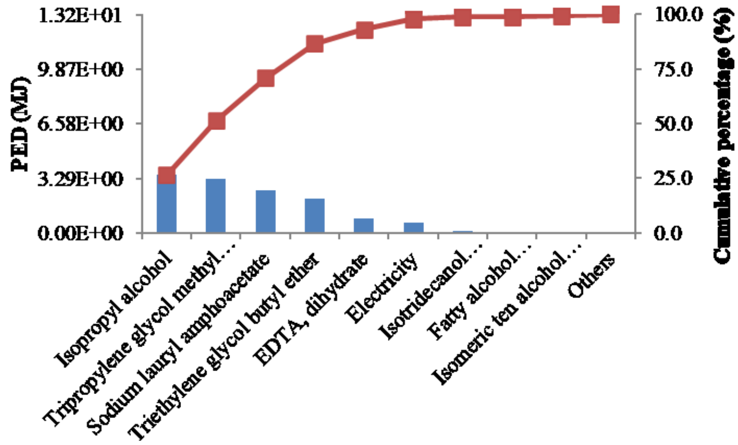

Figure 4. Primary energy consumption (PED) results of coke cleaning agent

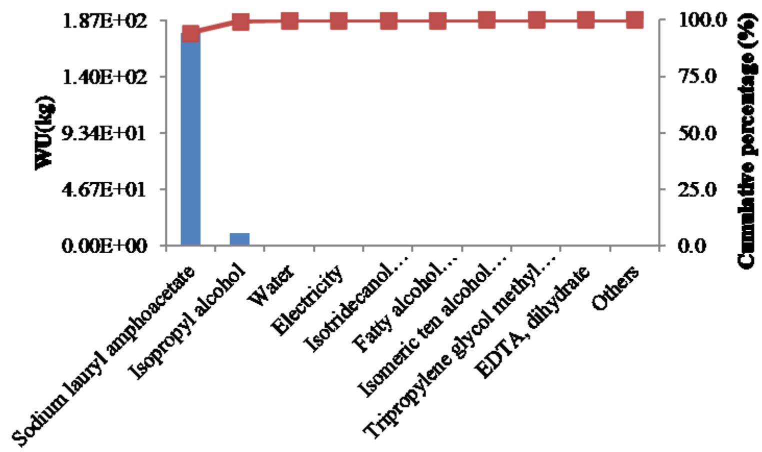

Figure 5. Water consumption (WU) results of coke cleaning agent

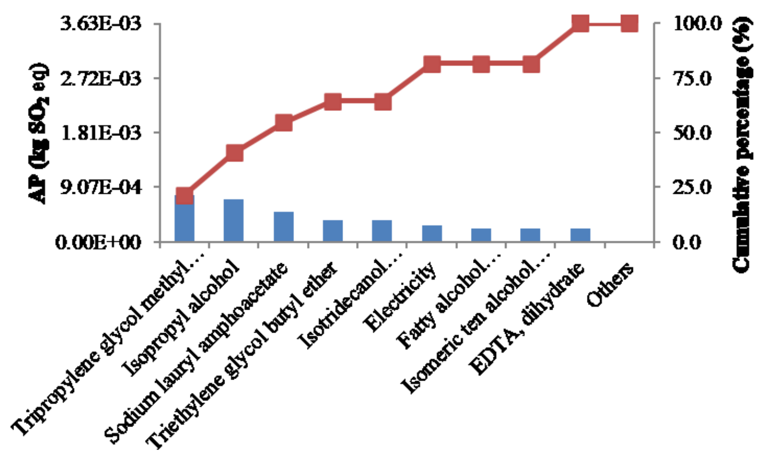

Figure 6. Acidification (AP) results of coke cleaning agent

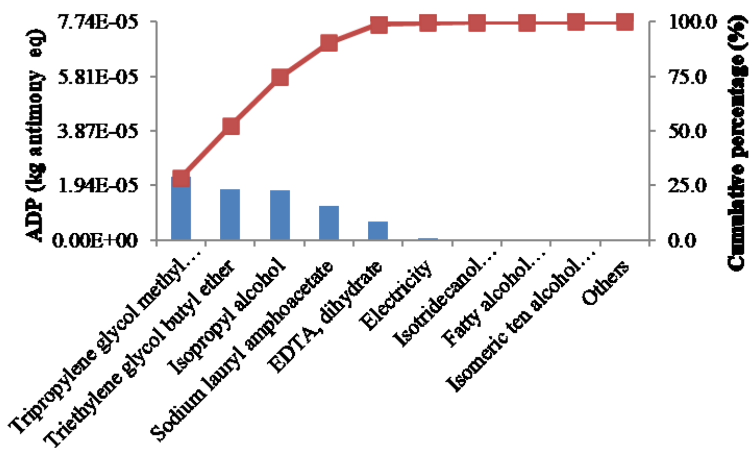

Figure 7. The results of abiotic resource consumption potential (ADP) of coke cleaning agent

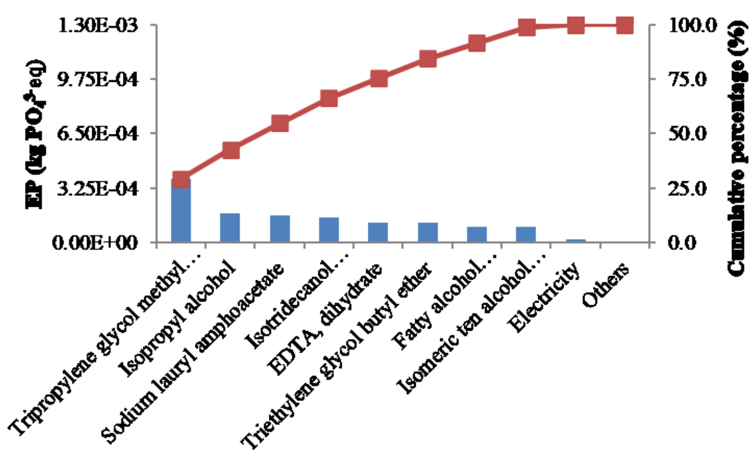

Figure 8. Eutrophication potential (EP) results of coke cleaning agent

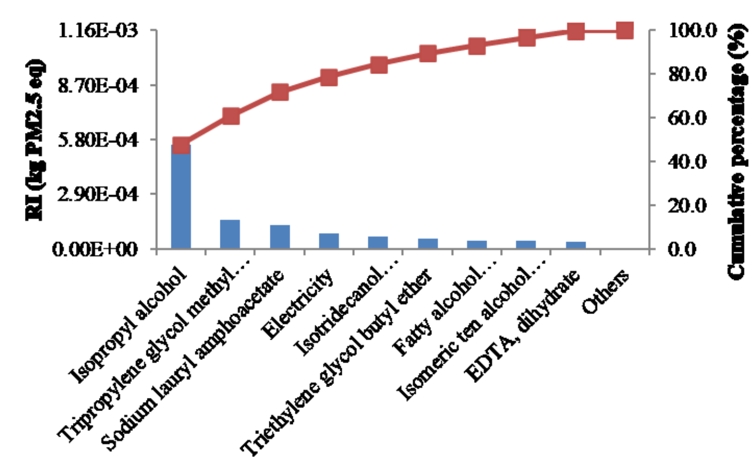

Figure 9. The results of inhalable inorganic matter (RI) of coke cleaning agent

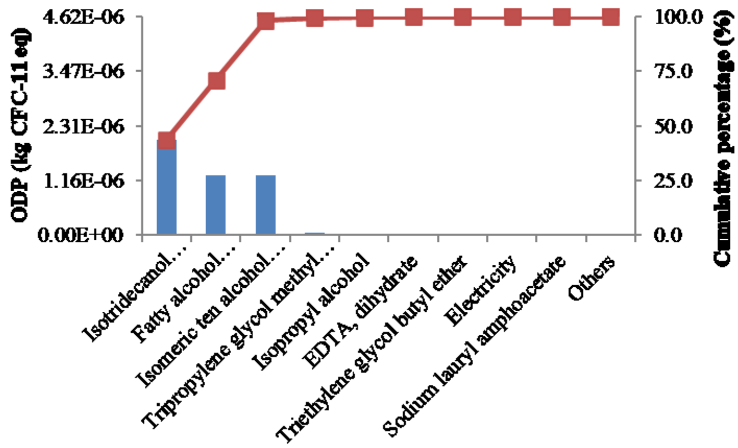

Figure 10. Ozone depletion (ODP) results of coke cleaning agent

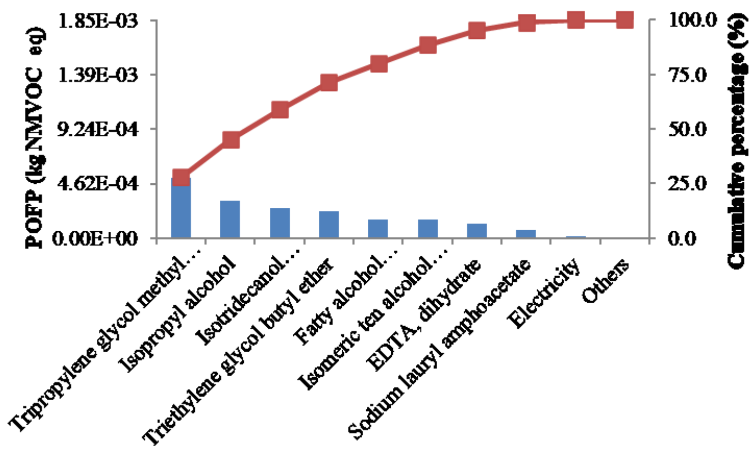

Figure 11. The results of photochemical ozone synthesis (POFP) of coke cleaning agent

Inventory Data Sensitivity Analysis

Inventory data sensitivity refers to the corresponding indicator change rate caused by the unit change rate of inventory data. By analyzing the sensitivity of the inventory data to each indicator, and with the improvement of potential evaluation, the most effective improvement points can be identified.

The inventory data sensitivity of the coke cleaning agent and sodium lauryl amphoacetate are shown in Table 5 and Table 6, respectively.

According to the average sensitivity (contribution rate) analysis:

(1) The five processes with the highest average sensitivity were the production of sodium lauryl amphoacetate 20.27%, isopropanol 18.93%, tripropylene glycol methyl ether 17.62%, isotridecanol polyoxyethylene ether 11.70% and freshwater 10.46% in the process of sodium lauryl amphoacetate. The high water consumption in the production of sodium lauryl amphoacetate may be due to the fact that the last step in the production reaction requires the use of sodium hydroxide solution for acid-base neutralization. Dissolving the solid sodium hydroxide requires a large amount of water. The heat released by the neutralization reaction needs to be absorbed by a large amount of water.

Table 5. Table of inventory data sensitivity of coke cleaning agent

Process	GWP	PED	WU	AP	ADP
Sodium lauryl amphoacetate	12.23%	19.59%	94.23%	13.83%	15.67%
Isopropanol	17.93%	26.59%	5.26%	19.25%	22.61%
Tripropylene glycol methyl ether	12.13%	24.68%	9.34E-04%	21.51%	28.82%
Isotridecanol polyoxyethylene ether	19.77%	0.91%	0.02%	9.8%	0.14%
Triethylene glycol butyl ether	5.68%	15.97%	1.83E-04%	9.99%	23.43%
Fatty alcohol polyoxyethylene ether M	12.36%	0.57%	0.01%	6.13%	0.09%
Isomeric ten alcohol polyoxyethylene ether	12.36%	0.57%	0.01%	6.13%	0.09%
Disodium EDTA, dihydrate	3.55%	6.4%	2.09E-04%	5.98%	8.43%
Electricity	3.98%	4.7%	0.1%	7.36%	0.72%

Table 5. Table of inventory data sensitivity of coke cleaning agent (continued)

Process	EP	RI	ODP	POFP	Average sensitivity
Sodium lauryl amphoacetate	12.25%	10.93%	6.05E-04%	3.71%	20.27%
Isopropanol	13.35%	47.89%	0.32%	17.19%	18.93%
Tripropylene glycol methyl ether	29.29%	13.15%	1.16%	27.84%	17.62%
Isotridecanol polyoxyethylene ether	11.39%	5.8%	43.64%	13.85%	11.70%
Triethylene glycol butyl ether	9.08%	4.84%	0.13%	12.51%	9.07%
Fatty alcohol polyoxyethylene ether M	7.12%	3.63%	27.28%	8.66%	7.32%
Isomeric ten alcohol polyoxyethylene ether	7.12%	3.63%	27.28%	8.66%	7.32%
Disodium EDTA, dihydrate	9.12%	3.24%	0.2%	6.52%	4.83%
Electricity	1.27%	6.88%	2.62E-03%	1.07%	2.90%

Note: The average sensitivity of each component in the list is the average of the sensitivity of the 9 indicators, which are GWP, PED, WU, AP, ADP, EP, RI, ODP and POFP.

(2) In the carbon footprint (GWP), the top five processes with the highest sensitivity were the production of isotridecanol polyoxyethylene ether 19.77%, isopropanol 17.93%, isodecanol polyoxyethylene ether 12.36%, fatty alcohol polyoxyethylene ether M 12.36% and sodium lauryl amphoacetate 12.23%.

(3) Among the primary energy consumption (PED), the top five processes with the highest sensitivity were the production of isopropanol 26.59%, tripropylene glycol methyl ether 24.68%, sodium lauryl amphoacetate 19.59%, triethylene glycol butyl ether 15.97% and disodium EDTA, dihydrate 6.40%.

(4) Among water resources consumption (WU), the top five processes with the highest sensitivity were the production of sodium lauryl amphoacetate 94.23%, freshwater 94.18% and isopropanol 5.26%

(5) In acidification (AP), the top five processes with the highest sensitivity were the production of tripropylene glycol methyl ether 21.51%, isopropanol 19.25%, sodium lauryl amphoacetate 13.83%, triethylene glycol butyl ether 9.99% and isotridecanol polyoxyethylene ether 9.80%.

(6) In the non-biological resource consumption potential value (ADP), the top five processes with the highest sensitivity were the production of tripropylene glycol methyl ether 28.82%, triethylene glycol butyl ether 23.43%, isopropanol 22.61%, sodium lauryl amphoacetate 15.67% and natural gas 10.69%.

(7) Among the eutrophication potential value (EP), the top five processes with the highest sensitivity were the production of tripropylene glycol methyl ether 29.29%, isopropanol 13.35%, sodium lauryl amphoacetate 12.25%, isotridecanol polyoxyethylene ether 11.39% and disodium EDTA, dihydrate 9.12%.

Table 6. Table of inventory data sensitivity of sodium lauryl amphoacetate (unit:%)

Process	GWP	PED	WU	AP	ADP	EP	RI	ODP	POFP	Average sensitivity
Freshwater	0	0	94.18	0	0	0	0	0	0	10.46
Natural gas	0	6.4	0	0	10.69	0	0	0	0	1.90
Electricity	2.67	2.92	0.05	4.56	0.47	0.85	4.13	6.05 E-04	0.64	1.81
CO_2	7.44	0	0	0	0	0	0	0	0	0.83
Nitrogen oxides	0	0	0	3.5	0	1.81	1.99	0	0	0.81
Crude	0	2.5	0	0	4.2	0	0	0	0	0.74
SO_2	0	0	0	3.1	0	0	0.76	0	0.49	0.48
Nitrogen	0	0	0	0	0	4.1	0	0	0	0.46
Solar energy	0	4.07	0	0	0	0	0	0	0	0.45
Ammonia	0	0	0	2	0	1.04	0.4	0	0	0.38
PM2.5	0	0	0	0	0	0	3.08	0	0	0.34
Nitrate	0	0	0	0	0	2.35	0	0	0	0.26
Non-methane volatile organic compounds	0	0	0	0	0	0	0	0	1.92	0.21
Hard coal	0	1.2	0	0	0.17	0	0	0	0	0.15
Uranium	0	1.17	0	0	0	0	0	0	0	0.13
Phosphate	0	0	0	0	0	1.1	0	0	0	0.12
CO_2(fossil source)	1.08	0	0	0	0	0	0	0	0	0.12
Lignite	0	0.9	0	0	0.12	0	0	0	0	0.11
N_2O	0.39	0	0	0	0	0.27	0	0	0	0.07
CH_4	0.65	0	0	0	0	0	0	0	0	0.07
NO	0	0	0	0.34	0	0	0.2	0	0	0.06

Note: The average sensitivity of each component in the list is the average of the sensitivity of the 9 indicators, which are GWP, PED, WU, AP, ADP, EP, RI, ODP and POFP.

(8) Among inhalable inorganic substances (RI), the processes with the highest sensitivity were the production of isopropanol 47.89%, tripropylene glycol methyl ether 13.15%, sodium lauryl amphoacetate 10.93%, electricity 6.88% and isotridecanol polyoxyethylene ether 5.80%.
(9) Among the ozone layer depletion (ODP), the processes with the highest sensitivity were the production of isotridecanol polyoxyethylene ether 43.64%, the production of isomeric ten alcohol polyoxyethylene ether 27.28%, and the production of fatty alcohol polyoxyethylene ether M 27.28%
(10) In photochemical ozone synthesis (POFP), the processes with the highest sensitivity were the production of tripropylene glycol methyl ether 27.84%, isopropanol 17.19%, isotridecanol polyoxyethylene ether 13.85%, triethylene glycol butyl ether 12.51%, fatty alcohol polyoxyethylene ether M 8.66%.

Through comprehensive analysis, the production of tripropylene glycol methyl ether, the production of isopropanol, the production of sodium lauryl amphoacetate and the production of isotridecanol polyoxyethylene ether have a significant impact on every LCA index. So they are the focuses of technology improvement.

Product Improvement Project

Isomeric ten alcohol polyoxyethylene ether, isotridecanol polyoxyethylene ether and fatty alcohol polyoxyethylene ether M account for the highest proportion in the formula, and are the necessary active ingredients in cleaning products as surfactants. It is recommended to develop cleaner production processes or to partially replace such products with surfactants which have cleaner production processes.

Isopropyl alcohol and tripropylene glycol methyl ether also account for high proportion in the formula as organic solvents in the cleaning agent, which can speed up the penetration of the cleaning agent into the dirt. It is recommended to reduce the carbon footprint by appropriately reducing the amount of isopropanol through further research.

Life Cycle Explanation

Assumptions and Limitations Statement

In this study, the results of 9 indicators of the production process of the coke cleaning agent were calculated. Formulations are determined by this study and do not represent industry average emissions. The LCA study simplified the actual formulation, reducing the number of surfactants to 2, assuming similar emission data for the production processes of other surfactants in the original formulation.

The types of organic solvents were reduced to 2, assuming similar emission data for production processes of other organic solvents. When simulating the calculation process, only the energy consumption of the core equipment was calculated. It was assumed that when the number of the main equipment increased, only electricity was consumed, and the emissions of the process would not increase.

The data assumptions of each unit process model are described in table 7.

Table 7. Description of model assumptions

Process name	Model assumptions analysis
coke cleaning agent [Production]	The emission parameters of similar constituent compounds are similar, and the formulation is simplified. When the major equipment was added, only electricity was consumed, and the emissions of the process would not increase.
sodium lauryl amphoacetate [Production]	The technology with the same process and emissions was used, and the electricity consumption was localized.

Completeness Statement

Strict mass balance and energy balance calculations were carried out in the production process of coke cleaning agent. Literature research was carried out on the emission data, and the average value of many literatures was used.

The dataset of sodium lauryl amphoacetate includes upstream raw material, energy and other data subsets and all emission data. To avoid double counting of emission data, all input data except electricity was ignored.

Table 8. Summary table of materials with missing or omitted data in the production process of sodium lauryl amphoacetate

Consumption name	Upstream data source	Quantity unit	Weight ratio	Test result
exhaust gas	negligible	0.3861kg	38.61%	Low-value waste from upstream, negligible
clay	negligible	6.2476E-05kg	0.01%	Comply with the selection rule
manganese	negligible	1.5903E-06kg	0%	Comply with the selection rule
dolomite	negligible	1.0391E-06kg	0%	Comply with the selection rule
crude potassium salt	negligible	0.0093kg	0.93%	Low-value waste from upstream, negligible
bauxite	negligible	4.8775E-06kg	0%	Comply with the selection rule
limestone	negligible	0.0028kg	0.28%	Low-value waste from upstream, negligible
chromium	negligible	2.865E-06kg	0%	Comply with the selection rule
fluorite	negligible	1.1383E-05kg	0%	Comply with the selection rule

Note: * weight ratio = material weight * quantity / product weight;
* The weight ratio of total ignored materials = the weight ratio of missing data + the weight ratio that meets the selection rule.

Data Quality Assessment Results

The report adopted the CLCD quality assessment method and completed the uncertainty assessment of the model inventory data on the eFootprint system. The results of the data quality assessment are shown in Table 9.

Table 9. LCA data quality assessment results

Indicator name	Abbreviation (Unit)	LCA results	Result uncertainty	Upper and lower result limits (95% confidence interval)
Climate change	GWP(kg CO_2 eq)	1.158E+000	6.06%	[1.09,1.23]
Primary energy consumption	PED(MJ)	1.279E+001	6.31%	[11.98,13.6]
Water consumption	WU(kg)	1.866E+002	24.05%	[141.72,231.48]
Acidification	AP(kg SO_2 eq)	3.461E-003	4.65%	[3.30E-03,3.62E-03]
Abiotic resource consumption potential	ADP(kg antimony eq.)	7.716E-005	8.32%	[7.07E-05,8.35E-05]
Eutrophication potential	EP(kg PO_4^{3-}eq)	1.292E-003	4.78%	[1.23E-03,1.35E-03]
Inhalable inorganic substances	RI(kg PM2.5 eq)	1.110E-003	9.56%	[1.00E-03,1.22E-03]
Ozone depletion	ODP(kg CFC-11 eq)	4.637E-006	11.20%	[4.11E-06,5.15E-06]

The result uncertainty data was plotted, as shown in Figure 1-12, and the analysis showed that the result uncertainty was between 4.20% and 24.05%. The data source is credible. The results obtained from the analysis have a certain guiding effect on the design of the subsequent product as a real coke cleaning agent.

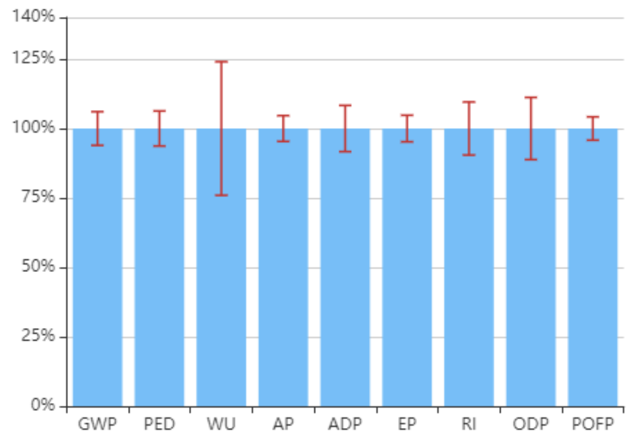

Figure 12. LCA result uncertainty

CONCLUSIONS

In this study, the life cycle of the developed coke cleaning agent was analyzed. The technology is phosphorus-free and environmentally friendly, which has a very broad market prospect. The life cycle model is cradle-to-gate (out of factory), and the background database included power grids, transportation and chemicals. Computer simulation was used to carry out strict mass balance and energy consumption balance on the production process. The study combined production plant data and published literature to analyze emissions.

(1) The life cycle model analysis of the established model showed that the climate change (GWP) of producing 1kg of coke cleaning agent was 1.19kg CO_2 eq; the primary energy consumption (PED) was 13.17MJ; the water consumption (WU) was 186.74 kg; acidification (AP) was 3.63E-03 kg SO_2 eq; abiotic resource consumption potential (ADP) was 7.75E-05 kg antimony eq; eutrophication potential (EP) was 1.30E-03 kg PO_4^{3-} eq; inhalable inorganic (RI) was 1.16E-03 kg PM2.5 eq; ozone depletion (ODP) was 4.63E-06 kg CFC-11 eq; and photochemical ozone synthesis (POFP) was 1.85E-03 kg NMVOC eq. The uncertainty of the results was between 4.20% and 24.05%.

(2) Carbon footprint (GWP) analysis showed that isotridecanol polyoxyethylene ether, isopropyl alcohol, fatty alcohol polyoxyethylene ether M and isomeric ten alcohol polyoxyethylene ether contributed the most.

(3) The average sensitivity analysis showed that the most influential process were sodium lauryl amphoacetate, isopropanol, tripropylene glycol methyl ether. Therefore they were the focuses of improvement.

(4) It was recommended to reduce the amount of isopropanol through research and development, and at the same time surfactants with cleaner production processes should be used to partially replace polyoxyethylene ethers to reduce carbon footprint.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this paper.

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