Life Cycle Energy Analysis and Evaluation of Retreaded Engineering Tires

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Abstract. In this paper, energy consumption models of retreaded engineering tires were constructed based on life cycle analysis, theoretical calculation model, and energy consumption method during the four stages of retreaded engineering tires, i.e., production, transportation, usage, and recycling stage. The energy substitute model and energy evaluation index during the recycling stage, which involves one of five classical retreaded engineering tire recycling methods, i.e., secondary retreading, mechanical smash, low-temperature smash, combustion decomposition, and combustion power generation, were presented. Life cycle energy analysis of retreaded engineering tires was conducted, and the energy consumption during the different life cycle stages was quantitatively analyzed, thus obtaining the energy restoration rate of the five classical recycling stages of retreaded engineering tires. Energy consumption analysis and energy evaluation at different stages were performed. Main conclusions indicate that the energy consumption during the production stage is the highest, and energy consumption during the transportation stage is the lowest. The energy recycling result of the secondary retreading or combustion decomposition of retreaded engineering tires is obtained.

1 Introduction

The output of Chinese tires can reach about two or three times the global average level and will account for 50% of the global output, and yearly productive capacity will be over 1 billion. In the future, China will become a major tire-producing country and the tire trading center of the world [1-3]. At present, about two hundred million old and useless tires are generated every year in China; this number will progressively increase at a surprising speed, thus resulting in the increasingly serious problem of "black pollution" [4-6]. At present, the yearly production capacity of engineering tires is about 10 million, which takes up about 1% of total tire production and accounts for about 8% of sale figures. Engineering tires are relatively larger than normal tires and have a weight that is about equal to that of several truck tires or tens of passenger tires. Moreover, the rubber resources consumed by engineering tires during production account for about 15% of total rubber; thus, the corresponding added value is about 30%–50% more than that of other tires [7-8]. Therefore, improving the operation rate of junk engineering tires, especially improving the retreading rate, will promote the development of the retreaded engineering tire industry. Studies on the effect of retreaded engineering tires on enterprises, society, and the environment lack a systematic approach, direction, quantitative analysis, and evaluation. For this reason, this paper constructs a consumption model of retreaded engineering tires considering the index of 26.5R25 retreaded engineering tire life cycle as the evaluation standard. It also qualitatively and quantitatively describes and evaluates the energy recovery rate (ERR) of five processing methods during the recycling stage of retreaded engineering tires. Lastly, it provides theoretic guidance to promote the application of retreaded engineering tires and policymaking of the retreaded tire industry[9-10].

2 Life cycle energy consumption analysis of retreaded engineering tires

The life cycle of retreaded engineering tires consists of four stages: tire production, transportation of raw materials and finished goods, tire usage, and recycling. Natural resources and energy are consumed in various degrees at every stage, and the recycle function of new resource and energy occurs at the recycling stage[9-10]. The recycling stage of retreaded engineering tires has been mainly studied through energy consumption analysis of five classical recycling techniques: secondary retreading, mechanical smash, low-temperature smash, combustion decomposition, and combustion power generation.

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3 Energy model of retreaded engineering tires' life cycle

3.1 Energy consumption model

An energy consumption model of the retreaded engineering tires' life cycle is built based on the first law of thermodynamics. The energy relationship at four stages is different. The corresponding energy function matches each stage. The energy consumption models of the retreaded engineering tires' life cycle constructed through superposition principle are shown in formula (1) .

$$TE = TE_1 + TE_2 + TE_3 + TE_4 \quad (1)$$

where TE is the total energy consumed; TE_1 is the energy consumed during the production stage; TE_2 is the energy consumed during the transportation stage; TE_3 is the energy consumed during the usage stage; and TE_4 is the energy consumed when old and useless retreaded engineering tires are recycled.

3.1.1 Energy consumption during production stage

The energy consumption of retreaded engineering tires during the production stage is influenced by consumed materials and energy, and it is calculated according to formula (2).

$$TE_1 = \sum_i (PM_i \times PM_{\rho_i}) + \sum_j (PE_j \times PE_{\rho_j}) \quad (2)$$

where TE_1 is the energy consumption during the production stage; PM_i is the raw material i consumption during the production stage; PM_{ρ_i} is the raw material energy density during the production stage; PE_j is the energy consumption of energy j during the production stage; and $PE_{\rho j}$ is the energy density of energy j during the production stage.

3.1.2 Energy consumption during the transportation stage

The transportation stage of retreaded engineering tires consists of three parts: from raw material to producing site, from producing site to sale site, and from the collection site of old and useless tires to the recycling disposal site. Energy consumption during the transportation stage is influenced by transportation method, transportation distance, and fuel used by transportation tools, and it is calculated using formula (3).

$$TE_2 = TD \times TE \times TE_\rho \quad (3)$$

where TE_2 is the energy consumption during the transportation stage; TD is the average running mile during the transportation stage; TE is the energy consumption amount during the transportation stage; and TE_ρ is the energy density during the transportation stage.

3.1.3 Energy consumption during the usage stage

The energy consumption of retreaded engineering tires during the usage stage is influenced by average running mile and used fuel, and it is computed using formula (4).

$$TE_3 = UD \times UE \times UE_\rho \quad (4)$$

In the formula, TE_3 is the energy consumption during transportation; UD is the average running mile during the usage stage; UE is the energy consumption amount during the usage stage; and UE_ρ is the energy density of the energy during the usage stage.

3.1.4 Energy consumption during the recycling stage

Energy consumption and energy recycling occur simultaneously during the recycling stage of retreaded engineering tires. The energy consumption of the retreaded engineering tires during the recycling stage is computed according to formula (5).

$$TE_4 = \sum_i (RM_i \times RM_{\rho_i}) + \sum_j (RE_j \times RE_{\rho_j}) \quad (5)$$

where TE_4 is the energy consumption; RM_i is the raw material i consumption amount; RM_{ρ_i} is the raw material i energy density; RE_j is the energy consumption amount of energy j ; and RE_{ρ_j} is the energy density of energy j .

3.2 Alternative energy model

New production and energy occur in the five classical recycling methods during the recycling stage of retreaded engineering tires, which are considered alternative energy during the research process and whose value is equal to the needed energy consumption during production. Its value during the recycling stage is calculated by formula (6).

$$AE = \sum_i (RPP_i \times RPE_{\rho_i}) + \sum_j (RPE_j \times RPE_{\rho_j}) \quad (6)$$

where AE is the alternative energy; RPP_i is the output of production i ; RPE_{ρ_i} is the energy density of production i ; RE_{ρ_j} is the output of energy production j ; and RE_{ρ_j} is the energy density of energy production j .

3.3 Energy evaluation index

NES expresses the relation between the production and consumption of alternative energy during the recycling stage of retreaded engineering tires, as shown in formula (7).

$$NES = AE - TE_4 \quad (7)$$

ERR expresses the recovery degree of input energy caused by five recycling techniques during the recycling stage of retreaded engineering tires. The ERR's value is the percentage ratio of how much output energy accounts for input energy during the recycling stage (mainly including energy consumption during the production and recycling stages), as shown in formula (8).

$$ERR = \frac{AE}{TE_1 + TE_4} \times 100\% \quad (8)$$

4 Result analysis

4.1 Energy consumption analysis

Table 1 shows the energy input–output list during the life cycle of one ton of retreaded engineering tires.

Table1. Energy input–output list during the life cycle of retreaded engineering tires

Category	Name	Value MJ/t Tire				
Energy consumption	Production stage TE_1	132913				
	Transportation stage TE_2	1103				
	Usage stage TE_3	10591				
	Resource stage TE_4	Secondary retreading	Mechanical smash	Smash at low temperature	Combustion decomposition	Combustion power generation
		33697	2401	53134	27139	483
Alternative energy	Alternative production of resource	124759	30437	30537	44763	9831
	NES	91062	28035	−22597	17444	9348
Evaluation index	ERR	74.88%	22.49%	16.41%	27.94%	7.37%

Table 1.shows that the energy consumption of one ton of retreaded engineering tires throughout its life cycle is about 144607 MJ. The maximum energy consumption of a retreaded engineering tire during the production stage is about 132913 MJ, which is about 91.91% of the energy consumption throughout its life cycle. The usage stage consumes about 10591 MJ, which is 7.32% of the energy consumption of a retreaded engineering tire throughout its life cycle. The last transportation stage consumes about 1103 MJ, which is 0.77% of the energy consumption of a retreaded engineering tire throughout its life cycle.

4.2 Energy evaluation

Figures1 and 2 show the maximum NES (91062 MJ) and the maximum ERR (74.88%), respectively, of five retreaded engineering tire recycling methods. The energy recycling results of the five retreaded engineering tire recycling methods are sorted in descending order, i.e., secondary retreading>combustion decomposition> mechanical smash>low-temperature smash> combustion power generation. Thus, secondary retreading is the most effective method of recycling retreaded engineering tires.

5 Conclusion

Energy consumption models and calculation method of life cycle of production stage, transportation stage, usage stage, and recycling stage of engineering retreaded tire were built based on life cycle principle. Energy consumption of engineering retreaded tire during production stage is max, which accounts for 91.91% of energy consumption of engineering retreaded tire life cycle, usage stage is next, which accounts for 7.32% of energy consumption of engineering retreaded tire life cycle, and last transportation stage accounts for 0.77% of energy consumption of engineering retreaded tire life cycle. Sort-order of energy recycling results of five kinds of recycling methods of engineering retreaded tire is descending, i.e. tire secondary retreading, combustion decomposition, mechanical smash, smash at low temperature, and combustion power generation. This shows that secondary retreading or combustion decomposition of engineering tire can be the most effective way for recycling of engineering retreaded tire.

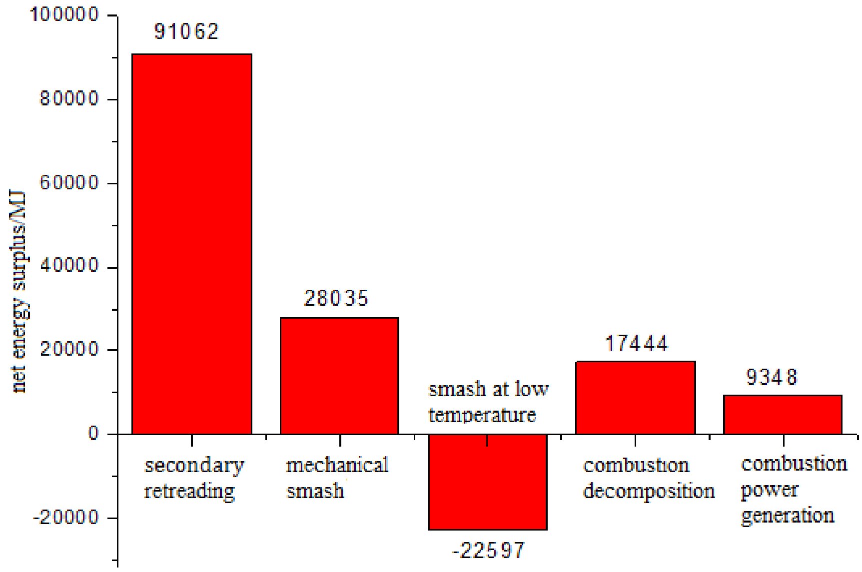

Fig 1. NES of five kinds of retreaded engineering tire recycling methods

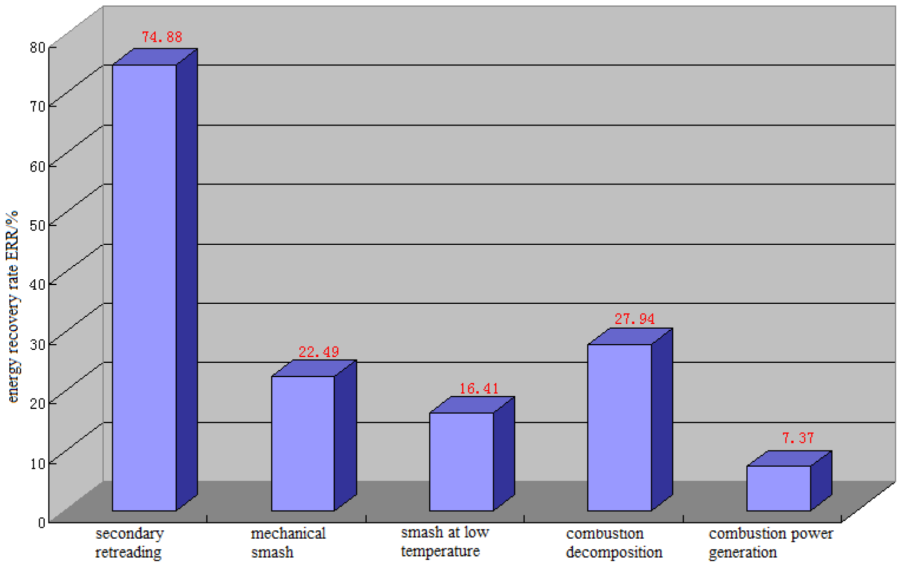

Fig 2. ERR of five retreaded engineering tire recycling methods

Acknowledgments

Fund Project: Project supported by basic scientific research business expenses of Heilongjiang Provincial Undergraduate Universities(2018CX07); Heilongjiang Natural Science Foundation Project(LH2019E115); Heilongjiang Institute of Technology PhD Research Startup Fund Project(2016BJ02) ;Heilongjiang Institute of Technology Provincial Leading Talent Echelon Cultivation Plan Project(2020LJ04).

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