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The application of Fuzzy Delphi Method and Fuzzy AHP in lubricant regenerative technology selection

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ABSTRACT

Due to the funding scale and complexity of lubricant regenerative technology, the selection of recycling technology and policy for waste lubricant oil can be viewed as a multiple-attribute decision process that is normally made by a review committee with experts from academia, industry, and the government. This study aims to provide a systematic approach towards the technology selection, in which two phase procedures are proposed. The first stage utilizes Fuzzy Delphi Method to obtain the critical factors of the regenerative technologies by interviewing the foregoing experts. In the second stage, Fuzzy Analytic Hierarchy Process is applied to find the importance degree of each criterion as the measurable indices of the regenerative technologies. This study considers eight kinds of regenerative technologies which have already been widely used, and establishes a ranking model that provides decision makers to assessing the prior order of regenerative technologies. The empirical study indicates that the "Proper scale" is the most important evaluation criterion considered in overall experts. The demonstration of how the prior order of regenerative technologies changes under various domains of experts is addressed as well.

1. Introduction

The efficient recycling of waste lubricant could help reduce both the environmental pollution and gas emission from greenhouses, thus, creating a huge efficiency either from environmentally-friendly or economic levels. Waste lubricant recycling and regeneration not only save the cost of lubricant, but also contribute to environmental protection. The proper management of dispose and recycling of the waste oil becomes critical to the management of environment (Cheng, Lin, Chang, & Huang, 2006/1). Regenerating waste oil into chemical feedstock or fuel oil is one of the preferred recycle methods.

At present, there are eight kinds of common lubricant recycling technologies as follows: (1) acid/clay process; (2) distillation process; (3) solvent de-asphalting process; (4) TFE + hydro-finishing; (5) TFE + clay finishing; (6) TFE + solvent finishing; (7) solvent extraction hydro-finishing and (8) TDA + clay finishing and TDA + hydro-finishing. These technologies are different in economic benefit, technology maturity and environmental impact, and new technologies have been developed and applied continuously. The government shall be responsible for technology assessment, and combine the views of academia, industrial circles and government sectors to set up a measuring index for selection of lubricant recycling technology.

The traditional Delphi Method, developed by Dalkey and Helmer (1963), has been widely used to obtain a consistent flow of answers through the results of questionnaires (Hwang & Lin, 1987; Reza & Vassilis, 1988). Delphi is an expert opinion survey method with three features: anonymous response, iteration and controlled feedback and finally statistical group response. However, some weaknesses have been exposed, it needs repetitive surveys to allow forecasting values to converge which requires much more time and cost (Hwang & Lin, 1987; Ishikawa et al., 1993). Furthermore, in many real situations, experts' judgments can not be properly reflected in quantitative terms. Some ambiguity will result due to the differences in the meanings and interpretations of the expert's opinions. Since people use linguistic terms, such as 'good' or 'very good' to reflect their preferences, the concept of combining fuzzy set theory and Delphi was proposed by Murray, Pipino, and Gigch (1985), and named the Fuzzy Delphi Method (FDM).

Lubricant regenerative technology selection is a multiple criteria decision-making problem. Among these, the Fuzzy Analytic Hierarchy Process (FAHP) is one of the most popular (Kahraman, Cebeci, & Ruan, 2004; Teng & Tzeng, 1996; Zhau & Goving, 1991). People often use knowledge that is imprecise rather than precise. The fuzzy set theory approaches could resemble human reasoning in use of approximate information and uncertainty to generate decisions. It was specifically designed to mathematically

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represent uncertainty and vagueness and provide formalized tools for dealing with the imprecision intrinsic to many problems (Kahraman et al., 2004; Williams, 2003; Zadeh, 1965). Consequently, to make this study more sensible and gain a more representative description of the decision-making process, this study would apply the FAHP to investigate which evaluation criterion is the most important in overall technical committees.

This study contains two stages: the first stage is to establish the key factors for evaluation of the waste lubricant recycling technologies, and use FDM by consulting experts of academia, industries and government sectors to select a technological selection criterion, in order to find out the important factors to be considered while selecting a technology; the second stage is based on FAHP, and consults experts of various fields to find out the importance of various criteria, in order to obtain the measuring index for selecting lubricant recycling technology.

2. Methodology

2.1. Fuzzy Delphi Method

Fuzzy Delphi Method was proposed by Ishikawa et al. (1993), and it was derived from the traditional Delphi technique and fuzzy set theory. Noorderhaben (1995) indicated that applying the Fuzzy Delphi Method to group decision can solve the fuzziness of common understanding of expert opinions. As for the selection of fuzzy membership functions, previous researches were usually based on triangular fuzzy number, trapezoidal fuzzy number and Gaussian fuzzy number. This study applied the triangular membership functions and the fuzzy theory to solving the group decision. This study used FDM for the screening of alternate factors of the first stage. The fuzziness of common understanding of experts could be solved by using the fuzzy theory, and evaluated on a more flexible scale. The efficiency and quality of questionnaires could be improved. Thus, more objective evaluation factors could be screened through the statistical results.

The FDM steps are as follows:

1. *Collect opinions of decision group*: Find the evaluation score of each alternate factor's significance given by each expert by using linguistic variables in questionnaires.
2. *Set up triangular fuzzy numbers*: Calculate the evaluation value of triangular fuzzy number of each alternate factor given by experts, find out the significance triangular fuzzy number of the alternate factor. This study used the geometric mean model of mean general model proposed by Klir and Yuan (1995) for FDM to find out the common understanding of group decision. The computing formula is illustrated as follows:
   Assuming the evaluation value of the significance of No. j element given by No. i expert of n experts is $\widetilde{w_{ij}} = (a_{ij}, b_{ij}, c_{ij})$, $i = 1, 2, \ldots, n, j = 1, 2, \ldots, m$. Then the fuzzy weighting $\widetilde{w_j}$ of No. j element is $\widetilde{w_j} = (a_j, b_j, c_j), j = 1, 2, \ldots, m$.Among which
   $$a_j = \underset{i}{Min}\{a_{ij}\}, \quad b_j = \frac{1}{n}\sum_{i=1}^{n} b_{ij}, \quad c_j = \underset{i}{Max}\{c_{ij}\}$$
3. *Defuzzification*: Use simple center of gravity method to defuzzify the fuzzy weight $\widetilde{w_j}$ of each alternate element to definite value S_j, the followings are obtained:
   $$S_j = \frac{a_j + b_j + c_j}{3}, \quad j = 1, 2, \ldots, m$$
4. *Screen evaluation indexes*: Finally proper factors can be screened out from numerous factors by setting the threshold α. The principle of screening is as follows:
   If $S_j \geqslant \alpha$, then No. j factor is the evaluation index.
   If $S_j < \alpha$, then delete No. j factor.

Schematic diagram of Fuzzy Delphi Method threshold is shown in Fig. 1.

2.2. Fuzzy Analytic Hierarchy Process

Laarhoven and Pedrycz (1983) proposed the Fuzzy Analytic Hierarchy Process in 1983, which was an application of the combination of Analytic Hierarchy Process (AHP) and Fuzzy Theory. The linguistic scale of traditional AHP method could express the fuzzy uncertainty when a decision maker is making a decision. Therefore, FAHP converts the opinions of experts from previous definite values to fuzzy numbers and membership functions, presents triangular fuzzy numbers in paired comparison of matrices to develop FAHP, thus the opinions of experts approach human thinking model, so as to achieve more reasonable evaluation criteria.

As for the experts' opinions, this study adopted the Similarity Aggregation Method (SAM) proposed by Hsu and Chen (1996) to integrate experts' weight values for various evaluation criteria, the fuzzy weight fraction of criterion of each hierarchy is obtained through the calculating mode of FAHP, and then the sequence of significance of each criterion is determined based on the hierarchy series connection and defuzzification mode.

Laarhoven and Pedrycz (1983) proposed the FAHP, which is to show that many concepts in the real world have fuzziness. Therefore, the opinions of decision makers are converted from previous definite values to fuzzy numbers and membership numbers in FAHP, so as to present in FAHP matrix.

The steps of this study based on FAHP method are as follows:

1. *Determine problems*: Determine the current decision problems to be solved, so as to ensure future analyses correct, this study discussed the "evaluation criteria for verification of credit card".
2. *Set up hierarchy architecture*: Determine the evaluation criteria having indexes to be the criteria layer of FAHP, for the selection of evaluation criteria, relevant criteria and feasible schemes can be found out through reading literatures and collective discussions. This study screened the important factors conforming to target problems through FDM investigating experts' opinions, to set up the hierarchy architecture.
3. *Set up fuzzy paired comparison matrices*: Compare the relative importance between factors given by decision makers in pairs, set up paired comparison matrices, after the definite values are converted to fuzzy numbers according to the definitions in Table 1 and Fig. 2, integrate the fuzzy evaluation values of experts based on the SAM concept proposed by Hsu and Chen (1996).
4. *Calculate fuzzy weight value*: Obtain the characteristic vector value of fuzzy matrix, namely the weight value of element. This

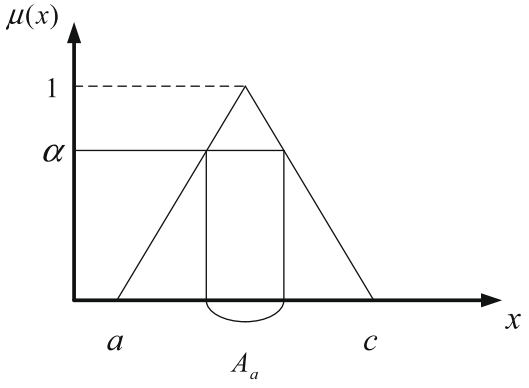

Fig. 1. Schematic diagram of Fuzzy Delphi Method threshold.