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Application of House of Quality in evaluation of low rank coal pyrolysis polygeneration technologies

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ABSTRACT

Increasing interest in low rank coal pyrolysis (LRCP) polygeneration has resulted in the development of a number of different technologies and approaches. Evaluation of LRCP processes should include not only conventional efficiency, economic and environmental assessments, but also take into consideration sustainability aspects. As a result of the many complex variables involved, selection of the most suitable LRCP technology becomes a challenging task. This paper applies a House of Quality method in comprehensive evaluation of LRCP. A multi-level evaluation model addressing 19 customer needs and analyzing 10 technical characteristics is developed. Using the evaluation model, the paper evaluates three LRCP technologies, which are based on solid heat carrier, moving bed and fluidized bed concepts, respectively. The results show that the three most important customer needs are level of technical maturity, wastewater emissions, and internal rate of return. The three most important technical characteristics are production costs, investment costs and waste emissions. On the basis of the conducted analysis, it is concluded that the LRCP process utilizing a fluidized bed approach is the optimal alternative studied.

1. Introduction

In China, as in other countries, the main direct use of coal is related to the production of electricity and heat. The other major applications of coal are its gasification and liquefaction. However, the both mentioned processes are low-efficiency methods [1]. The polygeneration processes could improve the use of raw material as well as limit environmental pollution [2,3]. In consequence, many polygeneration methods have been proposed [4–7]. One of the methods is low rank coal pyrolysis (LRCP) polygeneration. It is due to the fact that the low rank coal, including lignite, brown coal and subbituminous coal, constitutes more than 50% of the global coal reserves and the predictions show a possible considerable grow of its use in long term [8,9]. In China, there are three the most popular LRCP technologies based on [10–12]: solid heat carrier, moving bed process, and fluidized bed.

Polygeneration is a complex process, due to its multi-input and multi-output character, and cannot be evaluated effectively using a conventional thermal performance index. The input and output streams contain chemical products (such as methanol, ethylene, and propylene) and have energy potential (in the form of electricity, heat, etc.). Consequently, the design and optimization of polygeneration systems as well as the formulation of technical evaluation criteria becomes a non-trivial task [13].

Performance evaluation of polygeneration systems has been considered in a number of studies in the literature. Ma et al. [14], and Larson and Ren [15] proposed energy efficiency as a criterion for design and evaluation of a polygeneration system. Gao et al. [16] used exergy efficiency to evaluate a coal-based polygeneration process. Li et al. [17] suggested relative energy saving rate (ESR) as an overall performance indicator of a coal based polygeneration process. However, these indicators only consider the thermodynamic aspects of polygeneration, and they fail to comprehensively reflect the overall performance of the system.

In other work, Lin et al. [18] considered technical and economic performance in evaluation of coal-based polygeneration systems of synthetic fuel and power with CO_2 recovery. Salkuyeh and Adams [19] used thermal efficiency and net present value to evaluate a new power, methanol and DME polygeneration process. Li et al. [20] proposed techno-economic performance and cost reduction potential for evaluation of a substitute/synthetic natural gas and power cogeneration plant with CO_2 capture. While evaluations using such techno-economic indicators may be more reasonable,

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Nomenclature

AHP	Analytic Hierarchy Process
BJY process	low rank coal pyrolysis polygeneration based on a moving bed concept developed by the Beijing Power Economic Research Institute
CI	consistency index
CN	customer needs
CR	consistency ratio
DG	low rank coal pyrolysis polygeneration a solid heat carrier pyrolysis technique developed by Dalian University of Technology
ESR	energy saving rate
I_i	absolute correction importance weight of customer needs
Ki	customer needs weight related to process satisfaction
LRCP	low rank coal pyrolysis polygeneration
MI	market competitiveness index
TI	technical competitiveness index
P1	level of satisfaction with our product
P2	level of satisfaction with competitors' products
P3	target for customer demand satisfaction
P4	improvement ratio of the customer needs
P5	correction factors
P6	customer needs correction weights
P7	relative correction weights of customer needs
QFD	Quality Function Deployment
RI	random index.
R_i	improvement ratio
TC	technical characteristics
T_{aj}	absolute importance weight of technical characteristics
T_j	relative importance weight of technical characteristics
W_i	relative correction importance weight of customer needs
ZDL	low rank coal pyrolysis based on a fluidized bed concept developed by Zhejiang University

they fail to take into account the environmental performance of the polygeneration process.

In work aiming to provide a more comprehensive view, Azapagic et al. [21] proposed an evaluation criterion that included economic, environmental and social evaluation indicators. Carvalho et al. [22] proposed an evaluation criterion including efficiency, water consumption, pollution, human health and other key indicators, and Dou et al. [23] introduced an evaluation criterion with technical, economic, environmental and social evaluation indicators.

The above-mentioned evaluation methods are a considerable improvement on evaluation approaches based on a single thermodynamic indicator. However, they cannot effectively quantify the overall market and technical competitiveness of the different coal based polygeneration processes. There is, thus, a lack of quantitative indicators that can precisely and inclusively present the advantages and disadvantages of the different coal based polygeneration technologies available [24,25].

The House of Quality (HOQ) method is a potentially interesting approach to address the issue of evaluation of LRCP technologies. The HOQ method enables the translation of customer needs into the technical characteristics of the product or process under evaluation [26]. The simplicity and effectiveness of the HOQ method has made the approach widely used in the development of new and improved products/processes in many industries [27]. The method takes into consideration customer needs, the technical characteristics of the product/process and market conditions. The major application area of the HOQ method is identification of design targets on the basis of customer needs, technological difficulties and the competitive advantage of the product/process [28].

This paper applies the House of Quality method in evaluation of LRCP technologies to provide a basis facilitating rational selection of technology. It focuses on the formulation of key performance indicators, derived from the customer needs, as well as assessment of technical, economic, environmental, and competitiveness aspects applicable to the three LRCP approaches most commonly used in China: solid heat carrier, moving bed, and fluidized bed based processes [23,29].

2. Methodology

House of Quality (HOQ) is an element of the Quality Function Deployment (QFD) method. It uses a planning matrix to relate customer needs to the methods which the manufacturer of the product uses to meet these needs [30]. It considers the impact of customer needs ("whats"), technical characteristics ("hows") and market situation on the quality of the product.

A competitiveness matrix has been added to HOQ to better present the various factors influencing design and evaluation of the analyzed technologies. Based on the results of the HOQ, it is possible to establish priorities for the various customer needs and identify deficiencies in the compared technologies. This information can then be used in selection, adjustment, modification and optimization of the initial plan, thus enabling customer needs to be better satisfied and greater competitiveness to be achieved.

2.1. Structure of HOQ

An outline of the structure of HOQ, the core part of QFD, is presented in Fig. 1 [31]. HOQ is composed of the following generalized matrices:

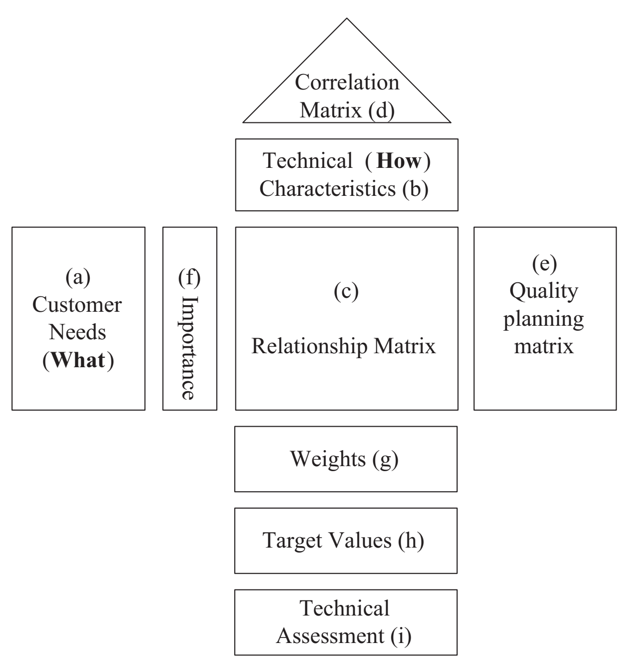

Fig. 1. Outline of the House of Quality.