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Soft-Sensing of carbon content of the catalyst in FCC based on deep learning

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Abstract: In this paper, a novel modeling method of soft sensing is presented to measure the spent catalyst's carbon content in fluidized-bed catalytic cracking. This model focuses on improving the existing soft sensing models' performances, such as higher measurement accuracy, more robust working performance, or better generalization ability. To build this model, firstly, we choose the primary variables and secondary variables by analyzing the mechanism model of fluidized-bed catalytic cracking. Secondly, we build a 4 layers deep belief networks as a feature extraction structure to extract feature data from the input data. And then we build an improved least squares support vector regression which is optimized by artificial bee colony algorithm as the regression structure. The extracted feature data will be the input to the regression structure. Thirdly, we use the catalyst related production data of 2# fluidized-bed catalytic cracking device from Sinopec Jiujiang Branch Corporation to train the model. The simulation results verify the effectiveness of the presented method.

Keywords: soft sensing, mechanism model, Deep Belief Networks, Least Squares Support Vector Regression, Artificial Bee Colony Algorithm, spent catalyst's carbon content, Fluidized-bed Catalytic Cracking

I. INTRODUCTION

The process of cracking and condensing of hydrocarbon of raw oil under thermic effect and catalyst conditions is called catalytic cracking, and FCC (Fluidized-bed Catalytic Cracking) is widely used at present. The catalytic cracking is one of the principal methods of oil's secondary processing [1]. The FCC process is composed of three parts: feed stock catalytic cracking, catalyst regeneration and production separation. The coked catalyst from settler separation process is called spent catalyst. The attached coke will be removed from the surface of the catalyst at regenerator's burning process, and the processed catalyst is called regenerated catalyst [2]. The flow of catalyst in FCC process is shown in Fig. 1.

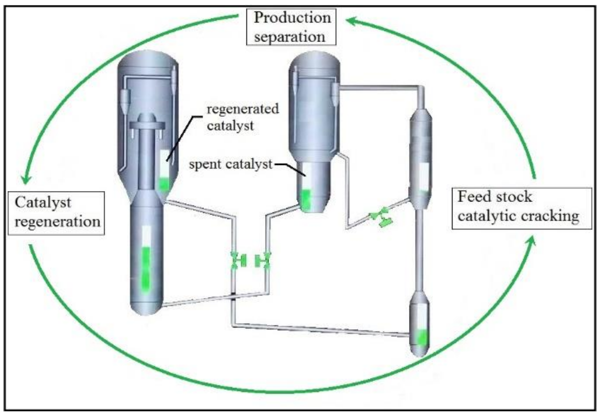

Fig. 1: The flow of catalyst in FCC process

The activity of catalyst is directly affected by its surface area covered by coke, the spent catalyst's carbon content should be usually controlled at around 5% [3]. Therefore, the detection of carbon content of the catalyst has a great significance to ensure a safe and stable production process environment, guarantee the yield of cracking products and prolong the catalyst's service life in FCC.

There are three main ways to measure carbon content of the catalyst: artificial sampling, online analyzer and soft sensing. The artificial sampling method can't meet the demand for real-time control as it has a long analysis period. The high price of equipment makes the online analyzer not suitable for industrial production. Soft sensing technique is an effective method to address this kind of problem as it can overcome the time lag problem of off-line artificial sampling and analysis, and has a high effectiveness-cost [4] [5].

Recently, methods of soft sensing based on artificial intelligence have been proved good measurement performance [6]. Li X [7] proposes a soft sensing model based on LS-SVM (Support Vector Machine) and applies it in the process of high pressure digestion of Alumina. Shengli LU [8] and Wei WX [9] use ANN-based (Artificial Neural Network) soft sensing modeling in measurement of water-flow at outlet of irrigation channel in yellow river and traditional Chinese drug inspissation process

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separately. In [10], a soft sensing model based on PCA (Principal Component Analysis) and BP neural network is introduced for coal powder amount in medium speed mill. And Wang JG [11] proposes a soft sensing method based on deep learning for operation optimization of coke dry quenching process.

However, all the existing soft sensing models still have some problems when applied in FCC process, especially in the measurement accuracy, reliability and generalization ability. In order to improve the precision and reliability of the soft sensing model of carbon content of the catalyst in FCC, a novel soft sensing model based on deep learning is proposed in this paper. This soft sensing model is composed of the feature extraction structure and the optimized regression structure. In the feature extraction structure, a network is composed of 4 layers of RBM according to DBN (Deep belief Network) algorithm. By extracting feature data from the high dimension input data, the feature extraction structure can eliminate the influence of noise signal in input data and improve the generalization ability of soft sensing model [12]. The optimized regression structure is composed of LSSVR (Least Squares Support Vector Regression) [13] and ABCA (Artificial Bee Colony Algorithm) [14]. In this structure, an artificial bee colony algorithm is used to optimize a least squares support vector regression structure by setting the parameters (σ, γ) of LSSVR as the optimization object of ABCA. The simulation result shows that this optimized soft sensing model has improvement both in measurement accuracy and reliability.

The remainder of this paper is organized as follows. The description of problem is shown in section II. The design method of soft sensing model is shown in section III and section IV shows the simulation results and analysis, also contrasts with other existing soft sensing models [15][16]. Finally, section V shows the conclusions.

II. PROBLEM & DESCRIPTION

In FCC process, the catalyst is involved in serval chemical operations and it is influenced by various kinds of environmental factors: factors related to the carbon content of the catalyst. In this paper, we select 6 kind of physical factors that are related to carbon content of the catalyst according to a mechanism analysis of FCC process: the flow of reforming feed stock, the temperature of reforming feed stock, the reaction temperature, the reaction pressure, the hydrogen-feed ratio and the catalyst circulation rate. According to the reaction-regeneration process (Fig. 2) of Sinopec Jiujiang Branch Corporation, we choose 18 secondary variables (Table 1), and take the catalyst's carbon content c_{cat} as the primary variable. The primary variable's value is from the laboratory analysis result, and the 18 secondary variables are from the real-time sampling database according to the time delay. In this paper, the time delay is calculated by the reactors' size and the circulation rate of materials.

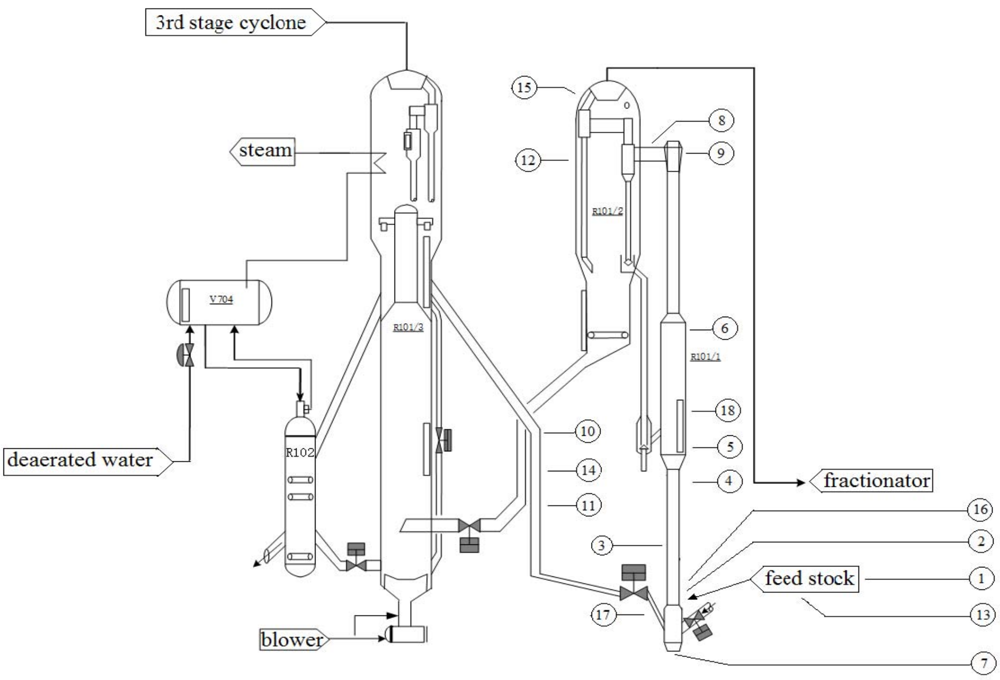

Fig. 2: The reaction-regeneration system of FCCU