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Research paper

Optimized temperature uniformity and pressure loss in the baking finish oven of the enameled wire

Ai Chun Ma, Yang Li*, Hong Li Dong

School of Energy Science and Engineering, Central South University, Changsha 410083, China

HIGHLIGHTS

- Temperature distribution and pressure loss in the hearth were optimized numerically.
- Temperature difference increases with branch air duct spacing increasing.
- Maximum temperature difference appears while the hearth width is 2488 mm.
- Optimal single-baffle and three-baffle air distribution device were proposed.

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ABSTRACT

The paper deals with the temperature uniformity and pressure loss in the hearth of the baking finish oven of the Enameled Wire with catalytic combustion and circulating flow. A numerical model of a RXHW3600 24-wire baking finish oven is built by Fluent, which is validated by the experimental velocities of the cold flow. The maximum temperature difference along the width direction of the hearth (MAX ΔT) and the pressure drop along the computational domain (MAX ΔP) are mainly investigated numerically. It shows that the MAX ΔT is too high, which will lead to a poor wire quality and large energy consumption. The MAX ΔP is very high too, which will increase the power loss. Detailed numerical work is carried out to investigate the correlations between the configuration parameters (branch air duct spacing, hearth width and air flow rate) and the MAX ΔT/MAX ΔP. Orthogonal method is used to determine the optimal structure parameters of the air distribution device. It is shown that the optimal air distribution device significantly reduces the MAX ΔT and the MAX ΔP. The MAX ΔT decreases by 79.1% and the MAX ΔP decreases by 37.8% respectively after optimization for the single-baffle structure. The MAX ΔT decreases by 78.1% and the MAX ΔP decreases by 42.9% after optimization for the three-baffle structure.

1. Introduction

There is a large production and demand of enameled wires in China. The enameled wires are widely used in various electric facilities, such as dynamo, motor, telecommunication apparatus, various measuring meters and so on. Enameled wires with stable qualities are the guarantee for a good performance of these electrical facilities. The baking finish oven plays a key role in the production process. After annealing, the copper/aluminium wire is led into the baking finish oven and coated with an insulation polyester lacquer layer at the entrance, and then the lacquer layer will be baked and solidified in the hearth of the oven. The process will be repeated several times. After the lacquer layer is cooled and shaped, the insulated enameled wire is produced. There are two trends in development for the baking finish oven, high-speed and less-wire, and low-speed and multi-wire. The representative companies are MAG Co. and SICME Co. in Western Europe for the former and the Japanese company Kuhara for the later. The main trend of development in China is medium-speed and multi-wire [1].

The technology of catalytic combustion and circulating flow was widely used in the baking finish oven of the Enameled Wire [2]. The catalytic combustion of the solvent evaporated from the lacquer layer can generate a lot of heat, and part of the high-temperature flue gas circulates in the system that can provide enough heat for baking and solidifying theoretically. The investigation recently on

* Corresponding author.
E-mail addresses: liyang_nengyuan0602@csu.edu.cn, 455849705@qq.com (Y. Li).

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the baking finish oven is mainly on intensification of catalytic combustion and optimal control of the production process [3–10]. H. Vidal et al. investigated about the optimal catalysts [3,4] or solvent [5], and Z.X. Lin et al. proposed a new structure of catalytic combustion chamber [7], for a more sufficient combustion. M.F. Guiaraes et al. proposed a high speed and high resolution fine wire diameter measurement system [8]. X.Y. Tang designed a new kind of computer control system to realize the real-time monitor of the production procedure [9]. L.W. Bridges et al. proposed a new online quality measuring method in place of the old off-line technique known as Tangent Delta [10]. Some other researchers paid more attention on the pollution reduction of the exhaust gas of the baking finish oven [11,12]. The literature of heat transfer, fluid flow and pressure loss in the baking finish oven of the enameled wire have not been reported.

For lacking of theoretical guiding, most of the design and operation control of the baking finish oven of the enameled wire in China is based on the experiences, which results in a common unstable wire quality and high energy consumption. Little research has been done on the baking finish oven of the enameled wire at home, and few systematic theories and practical conclusions formulated [13–16]. S.Y. Su [13] and Z.X. Lin et al. [14] proposed some new kinds of baking finish ovens of the enameled wire, which remould the oven structure in an overall scale but not applicable to the existing oven in service.

Some researchers studied on the optimization process of similar industrial oven to the baking finish oven of the enameled wire. By morphing a curved pipe with a 180° bend into a partially curved configuration, M.R. Hajmohammadi et al. [17] accomplished a considerable reduction of pressure drop and entropy generation of the customarily used bend tubes. F. Pask et al. [18] demonstrated a generalized methodology of systematic approach to industrial oven optimization for better heat performance, pressure loss or energy saving. Mohsen Amini et al. [19] performed a similar optimization for the shell-and-tube heat exchange, with parallel optimization variables amount rising up to 11, and also introduced the use of genetic algorithm to solve the problem when these design parameters have contradictory effects on the two objective functions of optimization simultaneously. A. Ashrafizadeh et al. [20–22] proposed optimal methodology or algorithm for numerical solving of the thermal dynamic problems of several baking ovens. S. Kalaiselvam et al. [23] and Sang-Moon Lee et al. [24] focused on improving the thermal performance and pressure loss of the coolant fluid by optimizing the characteristics of the fluid pathway. The former optimized configuration parameters like louver angle, fin pitch, and ice slurry (coolant) flow velocity of the tube–fin heat exchanger in ice slurry HVAC system. The latter optimally designed the channel shape, dimensions and angles of zigzag flow channels in a double-face printed circuit heat exchanger. Ke Jin et al. [25] redistributed the air flow in coke oven to improve the temperature uniformity of the coke bed, by adjusting the air flow rate of different-positioned dampers.

Also, there is still little research on the optimal thermal performance of baking finish oven, especially on the fluid field distribution and temperature uniformity in the hearth, which largely affects the wire quality and operating stability. Thus the present paper focuses on improving the temperature uniformity along the width direction of the hearth and reducing the pressure loss along the oven. The medium-speed and multi-wire baking finish oven with catalytic combustion and circulating flow was conducted. The influencing factors of branch air duct spacing, hearth width, air flow rate and air distribution device structure on the temperature uniformity and pressure loss were analyzed, and the optimal structures of the air distribution device for the baking finish ovens with ultra wide hearth were proposed too.

2. Model formulation

2.1. Physical model

A RXHW3600 24-wire baking finish oven with catalytic combustion and circulating flow was considered here. Part of the hot gas from the catalytic combustion device flows through circulating fan, air distribution device and 24 branch air ducts, then it flows into the hearth. The hot gas transfers its heat to the oncoming wires in the hearth. After it flows through solidifying zone, evaporating zone (the solvent on the wires evaporates here), it flows into the catalytic combustion device with the entrained vapor of solvent and finishes a complete circulation. The entrained solvent vapor burns in the catalytic combustion device, in which a lot of heat is generated and provides sufficient heat for the baking finish process. The ignition temperature of the catalytic combustion is guaranteed by the electric heating tubes in the catalytic combustion device. There are also arrays of electric heating tubes installed on the bottom of the hearth, as shown in Fig. 1, which are just a supplemental heating device and running only when the temperature in the hearth is under the rated value. Normally, the electric heating tubes don't need to work if the temperature is well distributed with a temperature difference within 5° along the width direction of the hearth. Therefore these tubes are not considered in the present

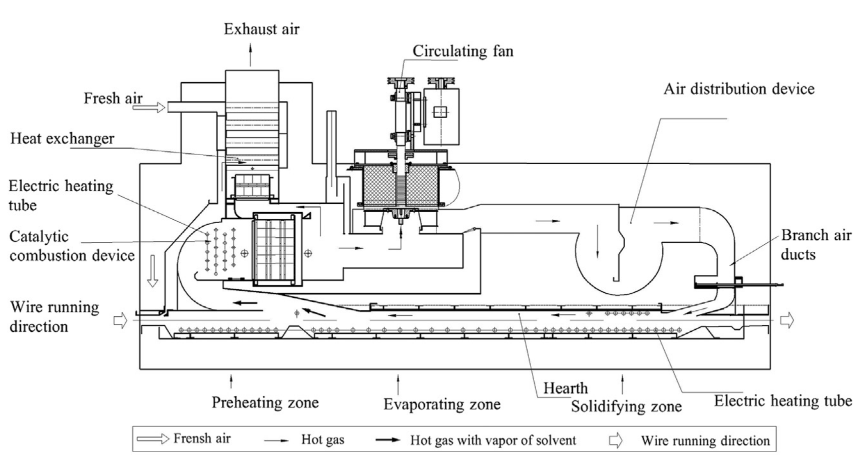

Fig. 1. Baking finish oven of the enameled wire.