Applied Thermal Engineering 78 (2015) 101–109

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research paper

A novel multivariate linear prediction model for the marine rotary desiccant air-conditioning by adding a dynamic correction factor

Jun Zhu [a], Wu Chen [a, b, *]

[a] School of Marine Engineering, Jimei University, Xiamen 361021, China
[b] Fujian Provincial Key Laboratory of Naval Architecture and Ocean Engineering, Xiamen 361021, China

HIGHLIGHTS

- A simple and high-accuracy prediction model is presented and performed by adding a dynamic correction factor.
- The accuracy and reliability of the new regression model is rather well.
- The convergence rate of regression model is extremely fast.
- The new methodology developed can be applied to other related fields.

ARTICLE INFO

Article history:
Received 18 August 2014
Accepted 22 December 2014
Available online 27 December 2014

Keywords:
Rotary desiccant air-conditioning
Dynamic correction factor
Multivariate linear regression
Prediction accuracy
Residual

ABSTRACT

Many research results suggested that a good estimation model often played a crucial role in the design, optimization and analysis for the HVAC system, especially during the preliminary design stage. Based on the multivariate linear regression analysis method, this paper presented a simple and high-accuracy prediction model by adding a dynamic correction factor. Newly developed model was not only particularly used to the marine rotary desiccant air-conditioning, but also its veracity and reliability were verified by a series of sample data and three evaluation indicators. Meanwhile, the prediction and optimization schemes of system performance are also introduced in detail. As expected, it was found that the dynamic correction factor can make the fitting value of prediction model close to the real value infinitely, and almost achieved linear fitting perfectly. As the number of correction increased, the residual and the residual standard deviation close to zero rapidly, and the relative error doubled decreased nearly. Besides, the square of multiple coefficient correlation (R^2) of the prediction models reached 0.999 after the seventh corrected and the relative error much less than 1%. Furthermore, it was believed that the methodology developed here can be applied to other related fields.

1. Introduction

In recent years, the rotary desiccant air-conditioning (A/C), as an efficient dehumidification and environmentally friendly technology, has been widely studied in the fields of industrial and civic buildings by combining with solar collector and evaporative cooling technology, and has a notable energy conservation effect [1]. However, the performance parameters of the rotary desiccant A/C are predicted and evaluated based on its structure parameters and operating parameters, which is one of the preliminary tasks must be carried out when the system is designed and calculated, meanwhile is also the premise of system performance optimization.

Due to the complexity and variability of the heat and mass transfer process in the desiccant wheel inside, the rotary desiccant A/C have been done by many researchers with its performance prediction. The mathematical model is an acceptable technique for assessing the rotary desiccant system, and has been playing an important role in the system analysis and optimization. Nevertheless, the mathematical model which can be restrained in a practical application because of it is too complex and time-consuming for predicting the rotary desiccant system [2–4]. In addition, the other well-known prediction methods also have been investigated for the rotary desiccant system, such as the artificial neural network method [5], the gray-box method [6], the interpolation method [7] and the multiple regression method [8].

* Corresponding author. School of Marine Engineering, Jimei University, Xiamen 361021, China. Tel.: +86 592 6181551; fax: +86 592 6180332.
E-mail address: chenwu73@163.com (W. Chen).

http://dx.doi.org/10.1016/j.applthermaleng.2014.12.049
1359-4311/

However, these common prediction methods have many weaknesses such as too complex or low-accuracy, so that the prediction effect often is not ideal. Consequently, a simple and high-accuracy prediction method is often preferred, especially during the preliminary design stage when different design concepts and system operation schemes are being considered. Obviously, this prediction method will no doubt be a challenge for the HVAC designers, especially using a simple prediction method that can represent, with enough accuracy, the behavior of the rotary desiccant A/C operating with variable parameters.

The multiple regression prediction method, which is the most common and basic, has been broadly recognized as a simple prediction technique. So far, there have been a lot of mature multiple regression algorithms which are a class of prediction and optimization techniques to solve the HVAC system and building energy consumption problems. For example, the references [9–12] where proposed the multiple regression models for the whole building as well as different HVAC systems can be used to predict the energy consumption. Besides, a simple multiple linear regression method for predicting the performance of the desiccant wheel has been proposed [8]. And the results show that the established regression model which can easily predict the behavior of the desiccant wheel by comparing predicted values to the experimental data. However, the form of built multiple regression model is fixed in these references, and the prediction accuracy could make a greater volatility with the changes of the external environment and system operating parameters. To overcome the aforementioned drawbacks, some researchers have put forward some suggestions to improve the multiple regression model form. Ge et al. [13] proposed a linear regression model to characterize the inner relationships among different users' rating habits. The major contribution of this model was that it can make more accurate predictions via utilizing the exact linear correlation indicated by Pearson Correlation Coefficient directly. Christian et al. [14] presented a novel linear model predictive control scheme. The main idea of this method was to make use of the fact that the dynamics of the initial prediction state was governed by the underlying continuous-time dynamics of the plant. Kubasova et al. [15] proposed a novel adaptive linear prediction model for lossless compression of hyperspectral images, which was an extended unification of 2-neighbour and 4-neighbour pixel context linear prediction schemes and was embedded in a lossless compression algorithm at the prediction phase.

The majority of researchers who in favor of a complex non-linear regression rather than a simple linear regression model when predict the system performance of the HVAC. That's mostly because the accuracy of the linear regression model is much lower than the non-linear regression model. Moreover, the relationship is often non-linear between the operating parameters and the performance parameters in the HVAC system. Therefore, whether make a few improvements on the basis of the multiple regression model to make the accuracy and stability of linear regression model and non-linear regression model equal or better than.

Based on such a consideration, this paper develop a novel multiple linear regression model by offering a dynamic correction factor, and it possibility to recognize the best prediction method and then to apply it to a marine rotary desiccant A/C to predict its system performance.

2. The description of the marine rotary desiccant A/C

The marine rotary desiccant A/C, which makes full use of the ships' residual heat and abundant seawater to handle the latent and sensible loads of the process air respectively and reduces the high-grade energy consumption, can achieve independent control the temperature and humidity of ship A/C. Fig. 1 illustrated the schematics of the marine rotary desiccant A/C system (a) and corresponding psychrometric chart (b). The marine rotary desiccant A/C system, which included two subsystems, namely the air handling system (1 and 8-2-3-4-5-6-7) and the wheel desiccant regenerating system (8-9-10), mainly consisted of an one-rotor two-stage desiccant wheel, an auxiliary refrigeration unit, a regeneration air heater and two seawater heat exchangers (exchanger 1 and exchanger 2).

The air handling system was as follows: the pre-process air (state 2) was the mixture of the fresh air (state 1) and the cabin return air (state 8) with a requirement ratio (the ratio of fresh air, $\geq$ 50%), which was dehumidified in the first stage dehumidification zone (I) of the desiccant wheel and the processed air temperature rose to state 3 due to adsorption heat effect. Then went into the first stage seawater heat exchanger (exchanger1) being cooled, and the temperature of the process air decreased to state 4. The process air after cooled by the exchanger 1, similarly, flowed through the second stage dehumidification zone (III), dehumidified again and the temperature went up to state 5, and cooled again by the second stage seawater heat exchanger (exchanger 2), the temperature of the process air changed to state 6. After that, the process air entered into the evaporator to cool rapidly, meeting the requirement of the supply air state 7, sent to the cabin by a fan (Fan1) final.

The wheel desiccant regenerating system was as follows: the regeneration air come from the cabin return air (state 8), heated by the regeneration air heater (heater) reached the regeneration temperature (state 9), then divided into two streams, led to regeneration zone one (II) and regeneration zone two (IV) respectively, to remove the moisture of dry sorbent and to recover dehumidifying capacity. Then the high-humidity regeneration air (state 10) was exhausted directly to the cabin outside.

3. Experimental setup and measuring instruments

3.1. Experimental setup

The experimental platform of the marine rotary desiccant A/C system was given in Fig. 2. In fact, the marine rotary desiccant A/C system is an integration of the solid desiccant wheel, the constant temperature and humidity air-conditioner, seawater cooling equipment (exchanger 1 and exchanger 2), the electric heater and the auxiliary refrigeration unit.

Considering the humidity of the marine air was higher and the cabin space was smaller, the honeycombed silica gel desiccant wheel of an one-rotor two-stage was used to dehumidify, which was divided into four parts including the first stage dehumidification zone (I), the regeneration zone one (II), the second stage dehumidification zone (III) and the regeneration zone two (IV). The angle of each dehumidification zone and each regeneration zone were 135° and 45° respectively; the diameter and thickness of the desiccant wheel were 450 mm and 200 mm respectively. To simulate the marine air states under any conditions, a constant temperature and humidity air-conditioner, which maximum power was 4.6 kW, was used to produce pre-process air. Its temperature and relative humidity control range were 20°C–40 °C and 50%–95% respectively, and control accuracy being within ±0.5 °C and ±2% respectively. In addition, two thermostatic water devices were configured in the experiment. One of them was used to simulate the different temperature seawater, sent to the exchanger 1 and exchanger 2 respectively; another was used to simulate cooling medium of the auxiliary refrigeration unit, sent to the heat exchanger (Evaporator). The operation and control of