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Butterfly valve erosion prediction based on LSTM network

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Highlights

- Simulation of fluid flow behavior under various conditions using DPM.
- Valve erosion intensifies over time and with increasing valve openings.
- LSTM networks can enhance the accuracy of erosion rate prediction.

Abstract

When valves and pipelines are used, erosion wear is a major concern. Erosion wear can lead to equipment downtime, material replacement, and other issues, as well as seal surface failure. The research delves into the phenomenon of erosion in butterfly valves, crucial components utilized across diverse industrial sectors. Erosion primarily affects the valve's disc and seat regions, leading to premature wear and compromised performance. To address this issue, the research employs computational fluid dynamics (CFD) and machine learning techniques, including long short-term memory (LSTM) and BP neural networks, to predict erosion rates under various conditions (different valve openings and particle diameters). Results indicate that erosion escalates with time and larger valve openings, highlighting the need for proactive maintenance strategies. The LSTM model demonstrates superior predictive capabilities compared to the BP neural network, offering valuable insights for improving butterfly valve design and operational efficiency in industrial settings. Furthermore, to seek a more efficient network configuration, the intelligent search capabilities of the particle swarm optimization (PSO) algorithm have been utilized to systematically explore the optimal network structure parameters. The prediction results highlight the advantages of LSTM in handling time series data, particularly in predicting erosion rates with complex dynamic characteristics.

Introduction

The butterfly valve, due to its simplicity, reliability, and ease of operation, is a preferred choice in numerous demanding industrial applications. However, with the increasing complexity of industrial applications and the emergence of aggressive fluid conditions characterized by high pressure, velocity, and corrosive nature, butterfly valves are often susceptible to erosion. As erosion progresses, leakage and sticking issues may arise, necessitating premature replacement. Monitoring the degree of erosion in operational valves will enable the prediction of their remaining lifespan, facilitating proactive maintenance or replacement and preventing potential production downtime or safety hazards [1,2].

Currently, scholars' research on butterfly valves mainly focuses on cavitation characteristics [[3], [4], [5], [6]], flow performance [7,8], manufacturing technology [9], structural optimization [10,11], hydrodynamic torque [12] and other aspects, but relatively little research has been conducted on the wear problem caused by fluid flow. When the butterfly valve is at a specific opening, the flow characteristics inside the pipeline have certain similarities with structures such as straight pipes, curved pipes, and grooves. By drawing on the wear research of other similar structures or valves, methods suitable for studying the wear inside butterfly valves can be summarized, providing ideas for related research. Fang et al. [13] established a physical model for particle-induced wear failure in electro-hydraulic servo valves and a corresponding wear life prediction model based on this physical model. The experimental results demonstrate that the physical model can accurately describe the degradation processes of various servo valves and estimate their wear lifespans accurately. Liu et al. [14] conducted solid particle erosion analysis on butterfly valves based on the erosion theory. A CFD model was established to simulate flow erosion, and different parameters such as inlet velocity, particle mass fraction, and solid particle diameter were analyzed. The results indicate that the erosion rate increases with the increase of inlet velocity, particle mass fraction, and solid particle diameter. The erosion of valve disks mainly occurs on the upstream edge and near the cylinder surface. Xu et al. [15] studied the solid-liquid two-phase flow characteristics, particle distribution, and erosion characteristics of butterfly valve piping under transportation conditions. They found that the addition of particles may enhance the high-speed regions behind the valve. Considering the complexity of solid-liquid two-phase flow, they used a DEM method for particle-particle forces and a DES turbulence model based on the realizable k-ε to investigate the flow characteristics and erosion mechanisms of butterfly valves under full-open transportation conditions. Li et al. [16] combined the discrete element method with CFD to simulate the erosion wear process of graphite sealing surfaces in high-temperature tri-eccentric butterfly valves under gas-solid two-phase flow conditions. They studied the erosion wear regularity of graphite sealing surfaces under different particle velocities, particle sizes, target materials, and operating conditions. Prashan et al. [17] used the Ansys discrete phase model to determine the most susceptible valve locations for erosion caused by impacting alumina particles under various pressure drops and valve closure angles. They also explored the feasibility of integrating laser scanning technology into the field of tribology and particle erosion analysis. Rehan et al. [18] studied a CFD-discrete particle model based on erosion prediction assessment, which was used to evaluate T- and Y-shaped pipe configurations under gas-sand and water-sand flow conditions. A comprehensive research was conducted on the erosion of pipes in vertical-horizontal directions under different particle sizes. The Finnie model was used to assess erosion rates, and it was validated using qualitative and quantitative experimental results from 90° T-shaped pipes. Peng et al. [19] considered gas particle slip in the sliding model to calculate the erosion of particles encapsulated in droplets in the gas core, and proposed a no-slip model to calculate the erosion of other particles in the gas core. A simplified numerical simulation method considering the cushion effect and gas particle slip was proposed to predict the corrosion rate of vertical bends. Liang et al. [20] used the CFD-DPM model to research the corrosion characteristics of solid air-liquid hydrogen pipelines. The research results are expected to provide theoretical basis for preventing liquid hydrogen pipeline corrosion. Ma et al. [21] used five sand concentrations and five particle sizes to simulate mud erosion on V-shaped grooves. The erosion resistance of V-shaped grooves was simulated using Fluent. The flow field near the V-shaped groove surface was analyzed to explain its erosion behavior. The simulation results were verified by corresponding experiments. Ma et al. [22] combined the wear prediction model to research the flow field, particle trajectories, flow resistance characteristics, and wear distribution on the main wall of gate valve pipeline systems. The accuracy of this method was verified through flow resistance experiments.

As a deep learning model, LSTM network is suitable for processing large-scale input data and can explore the time-series dependencies between data. It has rapidly developed in the field of prediction. Ran et al. [23] proposed a method based on the combination of deep belief networks and Mogrifier LSTM to predict the remaining useful life of lithium batteries. Experimental results show that this method has high effectiveness and superiority. Zhao et al. [24] introduced a method combining graph attention networks and LSTM to predict ship trajectories. Three real ship trajectory datasets from AIS were used to validate the effectiveness of the proposed model and compare it with other prediction models. Experimental results showed that the model had better evaluation metrics than other prediction models. Conrad [25] proposed a vibration prediction model based on the combination of adaptive noise-assisted complete ensemble empirical mode decomposition and LSTM network, according to the nonlinear and nonstationary characteristics of vibration in hydropower units. The parameters were optimized using an improved particle swarm optimization algorithm to improve prediction accuracy. The results indicate that the prediction model can effectively identify and predict vibration signals under different working conditions, providing theoretical support for fault diagnosis and safe and efficient operation of hydropower units. Yu [26] proposed an NGO-LSTM model for short-term photovoltaic power generation prediction, and conducted a case research using power data from a photovoltaic power plant in Andhra Pradesh, India. Simulation results indicate that the NGO-LSTM model has higher prediction accuracy and better prediction stability compared to BP, GA-BP, and LSTM models. This model can provide reliable references for adjusting grid planning and layout, optimizing power generation efficiency, and assisting in the operation and management of photovoltaic power plants. Li et al. [27] studied the relationship between different types of vehicle failures and battery data based on actual vehicle operation data from the large-scale monitoring platform of new energy vehicles. They proposed an online prediction method for electric vehicle battery failures based on LSTM. Experimental results indicate that the model based on the LSTM network can effectively predict battery failures with an accuracy rate exceeding 85%. Shan et al. [28] proposed a residual useful life prediction model called LSTM-DCGAN based on LSTM and deep convolutional generative adversarial networks. In the proposed LSTM-DCGAN, DCGAN is used to acquire knowledge from the training dataset, and then the pre-trained generator from DCGAN is attached to the LSTM network for further feature extraction. The effectiveness of the proposed LSTM-DCGAN is validated on the *C*-MAPSS aeroengine degradation dataset, and it is compared with other methods.

This research investigates erosion in butterfly valves using CFD simulations and machine learning techniques. The research utilizes the k-ε model for turbulence simulations and the Discrete Phase Model (DPM) in Fluent for solid particle erosion analysis. Additionally, LSTM networks are employed for erosion rate prediction, demonstrating superior performance compared to traditional methods. Overall, this research will promote the resolution of key issues related to butterfly valve corrosion, improve valve performance, lifespan, and industrial process stability and safety.

Section snippets

Geometrical model

The simplified structure of DN250 butterfly valve used in this research is shown in Fig. 1. The pipeline diameter is 250 mm, and the main structures include the valve plate, valve seat, and butterfly valve shaft. According to the guidelines of the valve flow testing experiment, the length of the upstream pipeline of the butterfly valve in the computational domain is extended to 13 times the diameter of the pipeline, and the length of the downstream pipeline is extended to 10 times the diameter…

Internal single-phase flow characteristics

The flow conditions inside a butterfly valve affect particle movement, thereby influencing the erosion of particles within the valve. Analysis of the single-phase flow characteristics inside the butterfly valve was conducted, and velocity contours and streamlines at different openings and times at the midsection of the valve were extracted, as shown in Fig. 6. From the figure, it can be observed that when the butterfly valve opening is small, due to the throttling and hindering effect of the…

Conclusions

The research concludes that erosion poses a significant challenge to the performance and longevity of butterfly valves in various industrial applications. Through CFD simulations and machine learning models such as LSTM and BP neural networks, the research provides valuable insights into erosion mechanisms and prediction techniques.

(1) Erosion primarily affects the disc and seat regions of butterfly valves, leading to premature wear and reduced operational efficiency. The severity of erosion…

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CRediT authorship contribution statement

Qingtong Liu: Writing – original draft, Supervision, Software, Methodology, Investigation, Conceptualization. **Chenghua Xie:** Software, Data curation. **Baixin Cheng:** Writing – review & editing, Software.…

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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