Advances of numerical simulation research on the emulsion flow field of wet skin-pass mill

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Abstract. Anti-rust agents are used as emulsion liquids to spray the roll gaps for wet skin-pass of cold-rolled steel strips. The wet-skin strip steel has a good shape, fewer surface defects, good anti-rust effect, higher strength, low roller consumption, and high work efficiency. Some research advances on the numerical simulation of the emulsion flow field in the wet skin-pass mill are discussed, including simplified two-dimensional nozzle models such as straight or convergent, high-pressure jets and conical converging nozzles to provide a theoretical reference for the numerical simulation of the emulsion flow field in the wet skin-pass mill.

1. Introduction
The wet skin-pass mill uses emulsion liquid at the inlet to spray work roll to remove various impurities attached to the working roll surface, thereby improving the quality of the steel plate products.

Studies on the numerical simulation related to the Emulsion fluid spray flow field mainly focus on high-pressure jets, ultra-high-pressure jets, and conical nozzles.

Most researches focus on the numerical simulation of the emulsion flow field in the wet skin-pass mill, using simplified two-dimensional nozzle models as straight or conical converging nozzles or other ultra-high-pressure jets.

2. High pressure water dephosphorization jet
High-pressure dephosphorization uses high-pressure water jets to remove oxide scale on the surface of steel billets, which is an important and common application of high-pressure water jets.

During rolling, the primary iron oxide scale will be distributed in flakes, bands, or dots, which affects the surface quality of the finished steel strip seriously. Therefore, with the rapid increase in the production of international and domestic steel plate, sheet, steel strip, and long steel in recent years, the control technology for removing oxide scale has become one of the key technical issues and hot research directions in the field of flat steel and long steel rolling.

However, due to the increasing requirements for the surface quality of steel strips and the need for removal of secondary oxide scale for long steels, the requirements for water phosphorus removal pressure, reasonable installation arrangements, jet interference size, descaling effect, and phosphorus removal nozzles have also become increasingly high. This field and the research of high-pressure water jet, emulsion liquid spray flow field, or other nozzle jet flow field should belong to the application of nozzle and injection technology in the non-combustion field.
G. J. Li et al. [1] conducted a theoretical study on the high-speed impinging flow of an ultra-high-pressure emulsion nozzle at a pressure of 300 MPa by using the Delaunay triangulation method. The numerical flow field has meshed, and the near-wall area with a large variable gradient was analyzed. Grid adaptation is used to obtain a more accurate solution. Besides, the SIMPLE algorithm and k-ε model are used in the FLUENT to analyze the velocity field, turbulent kinetic energy distribution, and the mechanism of shear stress refinement of fluid flow in the lead flow area, collision area, and jet area.

X. B. Zhu et al. [2] discussed the external velocity field and pressure field of a high-pressure phosphorus removal nozzle. They used Tgrid technology to generate unstructured hybrid grids. Numerical simulation of the unsteady flow field outside the nozzle under the inlet condition of 20 MPa is carried out by using the VOF model and Piso discrete algorithm. The flow characteristics of the jet flow field of the phosphorus removal nozzle were analyzed. The paper presents that the jet flow velocity near the optimal target distance will show a significant attenuation. The experiments have verified that the impacting pressure of the nozzle is inversely proportional to the target distance and directly proportional to the system pressure.

J. Li et al. [3] performed a CFD analysis on the automatic proportioning equipment of mining hydraulic device of the emulsion jet pump type and designed a cost-effective device, which solved the problem of low preparation accuracy of the original emulsion proportioning device. The preparation accuracy of the air-suction automatic proportioning device is increased from ±0.5% to ±0.2%, which improves the quality of preparation.

3. Flow field of emulsion nozzle of wet skin-pass machine

Q. Li et al. [4] used FLUENT to simulate the flow field in the three-dimensional cavitation nozzle, analyzed the pressure and velocity field distribution, and obtained the influence of different parameters on the impinging jet, which provided a basis for the optimal design of the jet nozzle.

S. Yan et al. [5, 6] used the S-A model in FLUENT and the SIMPLE algorithm to simulate the steady flow field inside and outside the target impinging jet nozzle of an ideal incompressible fluid. Due to the simplified structure and strong symmetry of the nozzle model discussed, the paper simplified the simulation model to a two-dimensional model, making the target impinging stream nozzle discussed and the common two-dimensional nozzle model closer. The author suggested that the target type nozzle is significantly better than the general centrifugal nozzle in terms of water-saving effect, and the larger working pressure and nozzle structure sizes, such as pipe diameter and target distance, can produce a better atomization effect.

G. L. Yang et al. [7-9] applied CFD technology to numerically simulate the incompressible jets inside and outside of the converging-diverging, conical, conical straight or rotating conical nozzle. In most cases, SIMPLY or SIMPLIC algorithm and two-equation k-ε or RNG k-ε turbulence model were chosen. Under the premise of the usage of simplified two-dimensional physical model, unstructured meshing established by GAMBIT automatic meshing technology and single-phase flow, the distribution characteristics of physical quantities, such as the velocity vector, pressure and turbulence kinetic energy of the flow field inside or outside the nozzle under certain conditions such as fixed initial pressure and nozzle outlet diameter and the change law of parameters such as nozzle length-diameter ratio, pitch or contraction cone angle during performance optimization were discussed.

L. Wang et al. [10, 11] discussed the pressure and velocity distributions of rolling cylindrical, conical, and parabolic nozzles respectively, and compared them with the actually measured flow rates and sweeping forces. There is still a relatively large gap between the nozzles mentioned above and the real three-dimensional skin mill nozzles with complex internal profiles for the reason that the two-dimensional simplified models were adopted and abrupt change in profiles was huge.

F. He et al. [12-14] of Tsinghua University used a two-dimensional numerical simulation method to study three simplified axisymmetric equal-diameter circular nozzles with different contraction angles or curves. The aerodynamic characteristics of the jet field such as flow field parameter distribution and retarding effect were researched. They used FLUENT software to simulate, and they verified that the RNG k-ε turbulence model is suitable for axisymmetric subsonic free jets based on the results of a large
number of numerical experiments. Besides, their supersonic free jet simulation scheme uses the S-A model.

H. L. Pan [15] of East China University of Science and Technology analyzed the influence of the emulsion inlet flow rate on the internal pressure of the emulsion and the pressure of the rolling plate, as well as the optimal inlet speed of the emulsion and the oil-water ratio through a two-dimensional FLUENT simulation.

4. Conclusion

The numerical simulation of the emulsion flow field of the wet skin-pass mill is one of the important research areas of cold-rolled steel strip and wet skin-pass. Some existing studies have achieved some important conclusions such as the distribution characteristics of the velocity, pressure, and turbulent kinetic energy of the liquid flow field from the simulation for two-dimensional straight, cylindrical, conical or parabolic tapered nozzle model and high-pressure jet and ultra-high-pressure jet when the nozzle structures changes. Although there are not many studies in this area, they provide useful guidance for the optimization of the performance of the emulsion flow field of the wet skin-pass mill.

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