U.P.B. Sci. Bull., Series D, Vol. 82, Iss. 1, 2020 ISSN 1454-2358

DESIGN AND SIMULATION OF CURVED NOZZLE FOR REMOVING THE FISH SCALE BY THE WATER JET

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In order to remove the fish scale by using water jet technology, a curved nozzle specially designed for this purpose is proposed. The modeling and simulation of the curved nozzle, the currently used cylindrical nozzle and the flat-fan nozzle are also completed. The simulation results show that the jet velocity contours ejected from the curved nozzles are C-shaped. Compared with cylindrical nozzles and flat-fan nozzles, the cleaning force distribution of the curved nozzle is more uniform, and the cleaning effect is better. Besides, the cleaning efficiency is higher. The curved nozzle proposed in this paper is more suitable for the water jet to remove the fish scale. In addition, the curved nozzle should also be fit for other cambered surface cleaning operation.

Keywords: The Water Jet, Remove Fish Scales, The Curved Nozzle, Fluent Simulation

1. Introduction

The high-pressure water jet is an important high-tech cleaning technology in the world. Pressurize water or other cleaning agents through the pump source, and we can see that a high velocity stream of water is then ejected from a nozzle with a special shape. The high-pressure water jet in the air is widely used in the manufacturing of cutting and cleaning operation. Water jet cutting is a plane cutting process for arbitrary patterns by continuously passing water jets with ultra-high pressure through solid materials [1]. Water jet cleaning involves the process of removing deposits from the surface of the materials. The jet ejected from the nozzle diffuses into the surrounding atmosphere through the air entrainment process to contact the surface to be cleaned, thereby generating a suitable striking force on the surface to be cleaned and removing the deposit from that surface for cleaning purposes [2]. When processing the fish, it is also of necessity to remove the scales for further refrigeration or cooking. Removal of the fish scale by the water jet, as an emerging technology, means to apply water jet

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cleaning technology to the removal of fish scales, and to use the impact force generated by water jets on the fish body to overcome the biological binding force of the fish body itself to the fish scales, thereby achieving the effect of removing fish scales [3].

The technology has the advantages of quick removal of fish scales, the high removal rate, low pollution, the low cost, etc., and has very good application prospects in future production practice. Internationally, BAADER of Germany, Arenco of Sweden and Toyo Aquatic Machinery Co., Ltd. of Japan have also carried out some research on this technology and developed certain equipment [4]. The nozzle on the machine for removing the fish scale by the water jet is the core component of the energy conversion in the fish scale removal process, and the core component of the effective striking jet is obtained. Whether the nozzle design is reasonable or not directly affects the fish scale removal effect[5]. The spray effect exhibited by the existing nozzle when dealing with the back of the curved fish body is not ideal.

Therefore, this paper proposes a curved nozzle for water jet removal of fish scales to raise its impact efficiency [6]. Combined with finite element analysis technology and CFD flow field analysis technology, we verify the feasibility and superiority of the nozzle by modeling it [7,8]. It is of great significance to improve the design of nozzles for water jet removal of fish scales in the future, and to upgrade the mechanized processing level of freshwater fish scale removal. At the same time, it provides a theoretical basis for the development of fish scale removal equipment.

2. Curved nozzle design

The nozzle is the energy conversion component of the water jet cleaning device. The design of the nozzle directly affects the dynamic performance of the nozzle water jet and the distribution of the external flow field. Among the existing nozzles, cylindrical nozzles (Fig. 1) and flat-fan nozzles (Fig. 2) are more commonly seen [9]. The cylindrical nozzle has the characteristics of large exit speed, good cohesion and small coverage [10]. The traits of the fan-shaped nozzle are: the spray range is wider; the jet velocity gradient decreases from the middle to both sides; the jet is uniform; the jet has a flat-fan shape [11].

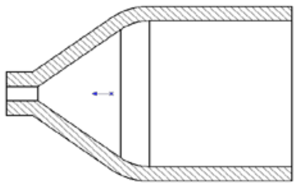

Fig. 1. Cylindrical Nozzle.

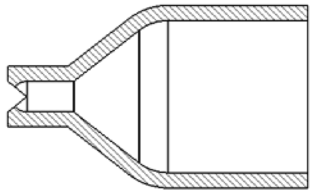

Fig. 2. Flat-fan Nozzle.

Considering that the shape of the fish body, as shown in Fig. 3 in the middle is higher than that on both sides, the jets ejected from the above two nozzles do not force the fish evenly during the process of striking the fish to remove the scales. It is not conducive to the removal of scales, but also damages the surface of the fish.

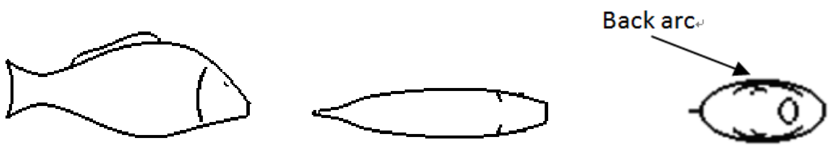

Fig. 3. Fish Body Model.

By studying the traditional type of the nozzle, we therefore propose a curved nozzle corresponding to the shape of the fish body. The physical model of the nozzle is shown in Fig. 4, and the sectional view is demonstrated in Fig. 5. The nozzle is provided with a water inlet chamber, an acceleration section passage, and a water outlet. The accelerating section passage is an accelerating contraction passage between the water outlet and the inlet chamber that is used for accelerating the water flow and ejecting a water jet to satisfy the force required for the removal of the fish scale. The central axis of the inlet chamber, the accelerating section passage and the outlet are all on the same line. The accelerating section channel is provided with two symmetrical arc-shaped inner side walls, and the inner wall thereof first decreases and then increases along the water flow direction. It can not merely achieve the effect of rapidly accelerating the water velocity, but also spray a densely-shaped and fan-shaped jet at the exit, thereby effectively increasing the range of impact on the fish body. The horizontal section at the water outlet is a circular arc section cut. Since the jet of the intermediate portion is first released from the inner wall of the nozzle and is in contact with the air, the speed is drastically reduced. The nozzle can eject a uniform jet, the velocity gradient of which gradually increases from the middle to the sides when the inlet pressure is constant. Therefore, it is suitable for fish structures that are higher in the middle. The impact force of the water jet on the fish body is homogeneously distributed to reduce the damage to the surface of the fish body. The scope of application of the nozzle is not limited to fish scale removal work, and should include some cambered surface cleaning operation [12].

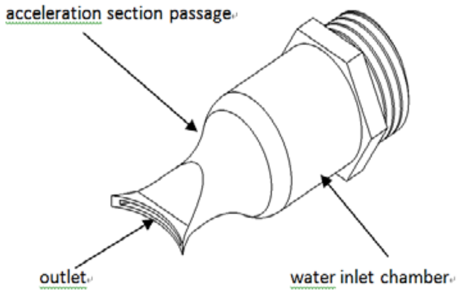

Fig. 4 Curved Nozzle Model.

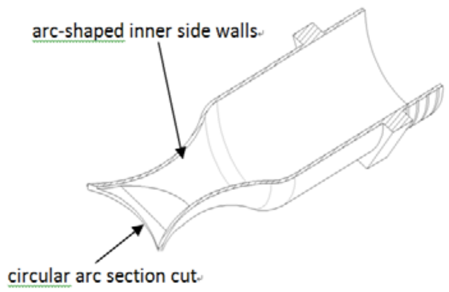

Fig. 5 Curved Nozzle Section View.

This paper uses fluid calculation software to simulate the injection of the external flow field of the nozzle. It analyzes the jet shape and velocity vector cloud generated under certain inlet and outlet pressure conditions and compares and analyzes the simulation results of cylindrical nozzles and flat-fan nozzles [13].

3. Research Method

Establishment of the curved nozzle model. We cannot build a model by using the Fluent software itself, and its own model-building software ICEM CFD can simply create some simple 3D geometry. The nozzle form designed in this paper is rather complicated and is unfit for ICEM CFD software. Therefore, this paper uses SolidWorks software to build the 3D model, and then import it into Fluent software for mesh division and the solution.

Determine the type of fluid flow. According to the definition formula of Reynolds number Re:

$$\mathrm{Re} = \frac{\text{Inertia force}}{\text{Viscous force}} = \frac{\rho v_1 D}{\mu} \quad (1)$$

In this equation,ρ=fluid density. kg/m^3;

μ=fluidviscosity, Pa•s; v_1=entrancespeed, m/s;

D = the nozzle inlet diameter, mm.

At a standard atmospheric pressure, the temperature is 20°C; the inlet velocity is 2 m/s; the Reynolds number is 2×10^7. Hence, the type of fluid flow in the nozzle is turbulent flow.

Since the outside of the nozzle is a gas-liquid two-phase subsonic turbulent flow, the Volume of Fluid model should be selected when selecting the multiphase flow model, which is very suitable for predicting the surface tension of jet breakup[14].This model can be chosen when it is desired to obtain an interface between one or more mutually incompatible fluids.In the Volume of Fluid model, different fluid components share a set of momentum equations, and the volume fraction occupied by each fluid component is recorded in each calculation unit of the full flow field.

Grid division. To study the jet velocity vector injected by the nozzle in the external flow field, a comparatively large cylindrical outer flow field is established at the nozzle outlet. It is used to simulate the two-phase gas flow field when the injected fluid leaves the nozzle and enters the air. We first import the built 3D nozzle model and the external flow field model into the geometry module, and define the boundary. Then, the meshing module in the Fluent software is meshed. In this paper, a combination of a hexahedral and tetrahedral mesh is used for meshing. And we try to use a hexahedral mesh to divide the model mesh. At the end of the meshing, a mesh quality check is performed to ensure the accuracy of the simulation results.

The calculation solution. Import the divided mesh files into the Fluentsoftware and check the divided mesh. If there is a mesh with a volume smaller than 0, we need to adjust the mesh type and the mesh size to re-mesh it. The solution process also includes determining of the algorithm, the definition of the materials, and setting of the boundary values. Iterative calculations are performed after initialization. Finally, the iterative results are analyzed, and the required conclusions are acquired [15].

In this paper, the nozzle fluid material is defined as ordinary tap water, which is the name calledin the material library. The density is 998 kg/m^3at 20 °C and the viscosity is 0.001 Pa·s. The standard $k-\varepsilon$turbulence model and the VOF model are used to simulate the whole gas-liquid two-phase flow field. Define air as the first phase and water as the second one; select the steady discrete solver, and set the water volume fraction to 1, meaning that the water fills the entrance; set the reflux volume fraction to 0, signifying that water is flowing from the outlet without reflux; the wall of the nozzle is defined as a non-slip wall and is solved using the SIMPLE algorithm. In addition, this paper adopts the pressure inlet boundary and the pressure outlet boundary. The boundary conditions are set as follows: the inlet pressure is 2MPa, and the outlet pressure is normative atmospheric pressure. The number of iteration steps is 1000.

Before applying Fluent software to iterative calculations, we first initialize the flow field. This paper chooses to initialize the entry speed.

4. Simulation Results

After the iteration convergence, we use the Fluent software for post-processing of CFD to process the external flow field of the nozzle, and obtain the external flow field velocity vector of the fish scale curved nozzle, as shown in Figure 6. To demonstrate the advantages of the fish scale removal nozzle more intuitively, Fluent simulations are performed on the cylindrical nozzle and the fan nozzle, respectively. The initial conditions are the same， and the velocity cloud maps concerning the two nozzle jets are shown in Figure 7 and 8, respectively.

It can be seen from Fig. 6 that the fluid ejected from the nozzle is accelerated by the accelerated contraction section and reaches a maximum value of 60.89 m/s at the outlet of the nozzle. Moreover, the design of the arc-contracting portion of the acceleration section can satisfy the densely-shaped fan-shaped jet having a large range of shearing ability. Due to the arc cut design at the nozzle outlet, the jet ejected from the middle portion is first removed from the inner wall of the nozzle, and the velocity is sharply reduced after being in contact with the air. Therefore, the jet velocity contour in the outer flow field is C-shaped. Considering that the shape of the fish body shown in Fig. 3 is higher in the middle, the jet from the nozzle will distribute the strike force uniformly when it comes into contact with fish scales. The fish scales on the fish body are subjected to the identical striking force, thereby greatly reducing the damage to the surface of the fish body and achieving a high-speed and effective fish scale removal effect.

It can be observed from Fig. 7 that the ordinary cylindrical nozzle has good cohesiveness and the stroke range is extremely limited, which is not conducive to the removal of the surface fish scales. The velocity of the middle part of the jet is obviously high, and it is rather easy to destroy the fish on the fish body when removing the fish scales, thus affecting the texture. It can be seen from Fig. 8 that the common fan-shaped nozzle has extensive impact, but the velocity of the jet is still larger in the middle than on both sides. When the fish scale is removed, the surface of the fish body is also damaged by the uneven impact force generated on the fish body.

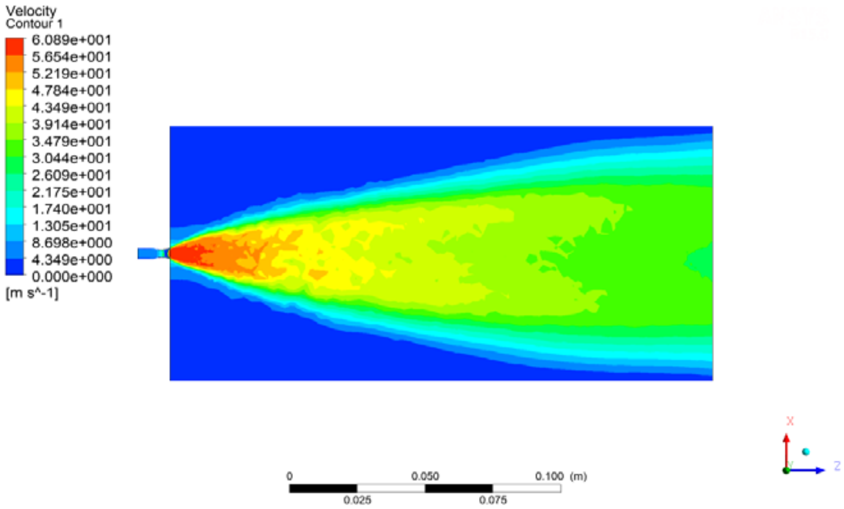

Fig. 6 Curved Nozzle Jet Velocity Distribution Cloud Map.

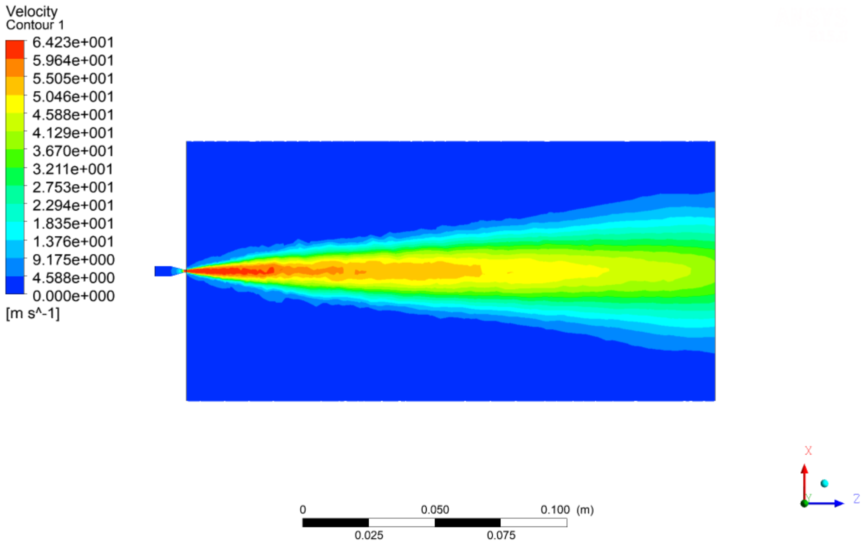

Fig. 7 Cylindrical Nozzle Jet Velocity Distribution Cloud Map.

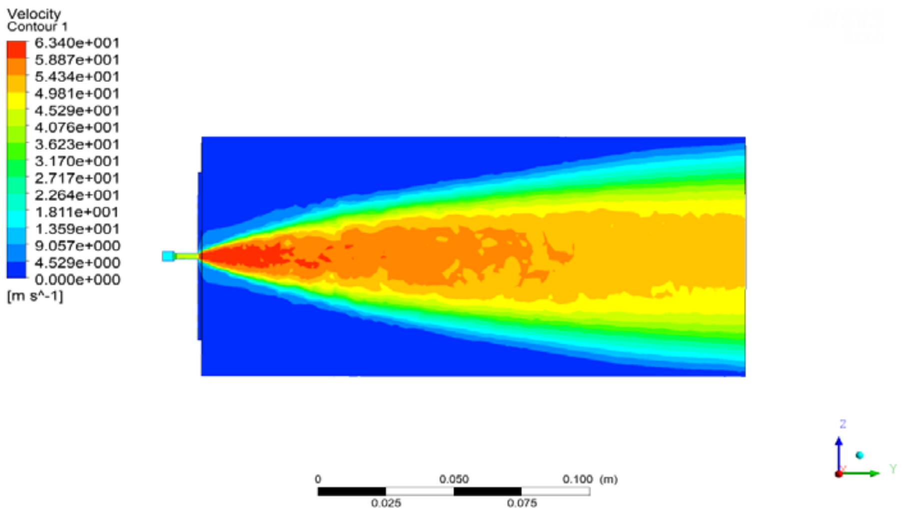

Fig. 8 Flat-fan Nozzle Jet Velocity Distribution Cloud Map.

Compared with the jetting effect of the three nozzles, the curved nozzle can evenly distribute the striking force on the fish body when facing the back-arc characteristic of the fish body, and the fish scale removal effect will be significantly better than the other two nozzles. When cleaning some intermediate surfaces that are higher than the sides, the curved nozzle can also improve the cleaning efficiency, for the striking force can be evenly distributed on the surface to be cleaned and the superiority is better than the other two nozzles.

5. Experimental Result

In order to verify the simulation results, we have processed the curved nozzles. And under the same conditions, the curved nozzle and the flat-fan nozzle were respectively subjected to the removal of the fish scale by the water jet.The experimental results are shown in Figures 9 and 10.As shown in the picture, since the middle portion of the water jet ejected by the flat-fan nozzle is faster than the surrounding speed, the middle portion of the water jet has a greater impact force, and the middle portion of the fish body is more damaged than other parts of the fish body.The curved nozzle can evenly hit the water jet to the fish body, so there is no obvious damage to the fish body. This proves that the curved nozzle is more suitable than other nozzles for removing the fish scale by means of water jet.

Fig. 9 Removed Fish Scales By CurvedNozzle.

Fig. 10 Removed Fish Scales By Flat-fan Nozzle.

6. Conclusion

This paper proposes a curved nozzle that is more suitable for the water jet to remove fish scales. Besides, it completes the modeling and simulation of this nozzle, the common cylindrical nozzle and the common flat-fan nozzle. The simulation results show that the contour of the jet velocity ejected from the curved nozzle proposed in this paper is C-shaped, which can spray a flat jet with better compactness. It is especially fit for removing fish scales with a fish body structure having a higher middle height than the sides. The feasibility of this type of the nozzle for fish scale removal work is verified. Finally, the comparison results of the cylindrical nozzle and the flat-fan nozzle are compared. Since the curved nozzle can evenly distribute the striking force on the fish body, the damage to the surface of the fish body can be reduced in comparison with the other two nozzles. The use of the nozzle is not limited to the removal of fish scales, but can also be used for some arc surfaces with similar characteristics to the fish body.

The next step in this study will be to establish a corresponding water jet experimental platform and conduct a study on the mechanism of removing fish scales by water jets using curved nozzles.

Acknowledgments

This work was supported by the National Key R＆D Program of China (GrantNo.2018YFD0400801); Liaoning Natural Science Foundation Project (Grant No.20180551017).

REFERENCES

[1]. *B. Betts.*The kindest cut [laser and water cutting]. Engineering and Technology. Vol.5 No.17 57-59. 2010

[2]. *Anirban Guha:* Ronald M. Barron and Ram Balachandar, An experimental and numerical study of water jet cleaning process. Journal of Materials Processing Technology. Vol.211 No.4.610-618. 2011

[3]. *Wang,Jiujiu; Zong,Li; Xiong,Shanbai*, Continuous scaling method for freshwater fish. Transactions of the Chinese Society of Agricultural Engineering.Vol.27 No.9. 339-343. 2012.

[4]. *Xv, ZW (Xv,Zhongwei),*The development direction and prospects of fish pretreatment equipment. Modern fishery information. Vol.12. 32-35. 2007

[5]. *E Ghassemieh1; H K Versteeg2; MAcar 2*, The effect of nozzle geometry on the flow characteristics of small water jets. Proceedings of the Institution of Mechanical Engineers. Part C, Journal of Mechanical Engineering Science. Vol.220 No.12 .1739-1753. 2006

[6]. *Juraeva, Makhsuda;Song, Dong Joo;Kang, Dong Jin,* Computational optimization approach to design a water-jet nozzle for a water-jet loom using the design of experiment method. Journal of Mechanical Science & Technology. Vol.33 No.2 .631-637.2019

[7]. *Li, HX (Li, H. X.); Li, B (Li, B.); Choi, J (Choi, J.);Heo, J (Heo, J.);Kim, I (Kim, I),* Analysis of a novel nozzle used for pulse jet filtration using CFD simulation method. International Journal of Simulation Modelling. Vol.15 No.2 .262-274. 2016

[8]. *Qiang, ZR; Wu, MP; Miao, XJ;* Sawhney, R, CFD research on particle movement and nozzle wear in the abrasive water jet cutting head. The International Journal of Advanced Manufacturing Technology. Vol.95 No.9-12.4091-4100. 2018

[9]. *Bursey, Sr.; Charles, Nozzle Knowledge.* Fuel Oil News. Vol.82 No.2. 50. 2017

[10]. *Moghe; Shashank S.Janowiak; Scott M*, Large Eddy Simulation of Cylindrical Jet Breakup and Correlation of Simulation Results With Experimental Data. Journal of Engineering for Gas Turbines & Power. Vol.139 No.10.1-10. 2017

[11]. *Lin, X; Liu, HL; Wang, GZ;Ke, J;Yu, LY,* Study on Low Pressure Jet Characteristics of Fan Nozzles. Machine tool and hydraulic. Vol.3.164-167. 2015

[12]. *J Lee, H Shin,* Parameter design of water jet nozzle utilizing independence axiom. Proceedings of the Institution of Mechanical Engineers. Part E, Journal of Process Mechanical Engineering. Vol.222 No.3 .157-169. 2008

[13]. *Cai,Y; Su,GB,*High pressure water jet nozzle design and finite element analysis. Mechanical design and research. Vol.33 No.6.163-167. 2017

[14]. James M. Dow. Just doing what I do: on the awareness of fluent agency. Phenomenology and the Cognitive Sciences,16(1). 2017

[15]. *CanliEyub; AtesAli; BilirSefik,*Comparison of turbulence models and CFD solution options for a plain pipe. EPJ Web of Conferences. Vol.180. 02013. 2018