MARITIME SOLUTIONS FOR A CHANGING WORLD

#172 - WINTER 2023

TERRA ET AQUA

RECOGNISING SAFETY INNOVATION

Boskalis' award-winning water box design

NUMERICAL STUDY ON A JET PUMP

Characteristics of internal mixture flow

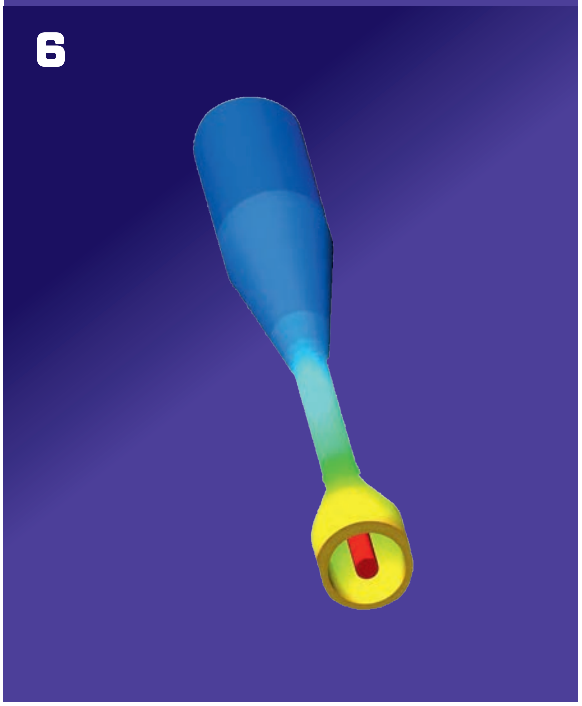
THE ŚWINOUJŚCIE – SZCZECIN FAIRWAY

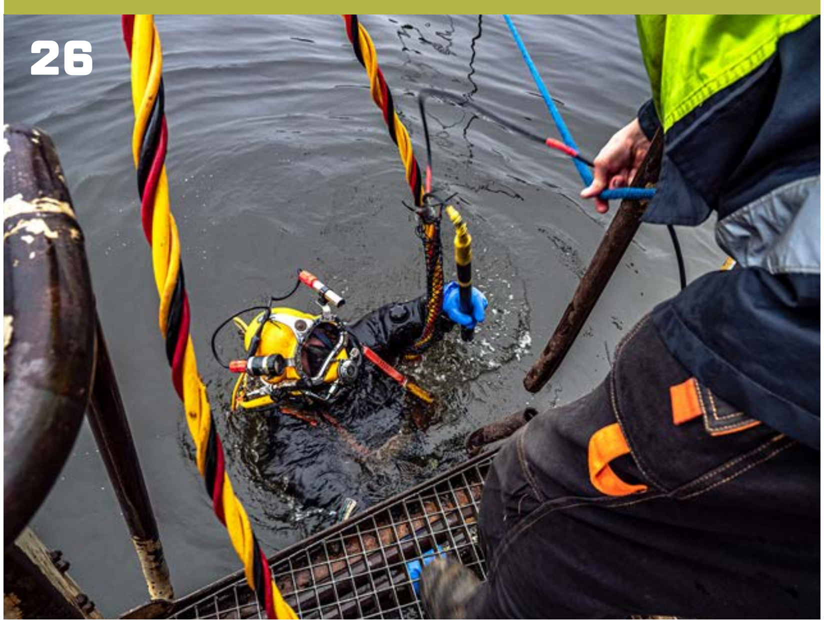
ONE OF THE MOST IMPORTANT DREDGING PROJECTS IN POLAND'S HISTORY

IADC SAFETY AWARD WINNER

This year's IADC Safety Award was presented to Boskalis for its new, modular design water box. The design modification means that, instead of going down to the water level in the landfill from the inside, personnel can now use a safe stairway to access a manually operated platform that allows them to move up and down the outside of the water box. Read the full article on page 20.

CONTENTS





SHARED COMMITMENT TO BEST PRACTICES

As 2023 draws to a close, we turn our attention to the coming year and the plans IADC has for the future. Our focus in 2024 will be our continuing drive for sustainability and how the dredging industry can ensure its commitment to conduct projects in respect to the three pillars of sustainability. As an example, to align with the energy transition, the industry is looking at the use of biofuels as a more sustainable alternative to fossil fuel and many companies are already running vessels on LNG.

In light of the consequences of climate change, the expertise contained within the field of climate-adaptive solutions is becoming ever increasingly important. In addition to the devastation caused by the continuing war in the Ukraine and more recently, the troubles between Israel and Palestine, this year has had its own share of natural disasters. The Paris Agreement and its goals remain at the forefront for individuals and companies alike the world over.

The expertise contained within the field of climate-adaptive solutions is becoming ever increasingly important.

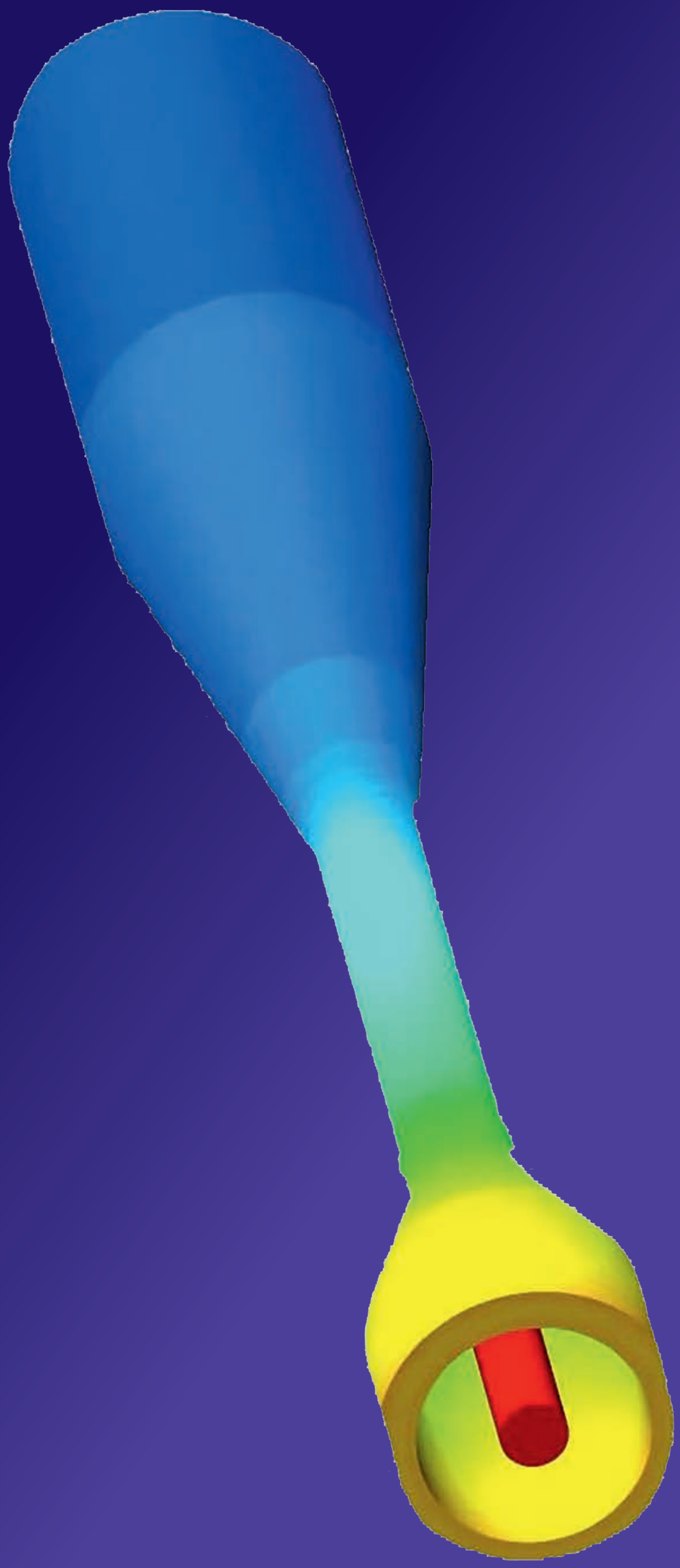
The publication of IADC's paper, Sand as a resource: best practices to conduct responsible dredging projects, puts forward the steps needed toward environmental standards in regard to managing this infinite resource. As a sector, the dredging industry has extensive expertise in the sustainable extraction of sand and its goal is to share its experience and findings with a broader audience to advise other industries and stakeholders in sustainable practices. Taking these concerns to heart is the shared responsibility of dredging contractors, project designers, project owners and authorities, and IADC advocates for the social and environmental benefits gained as part of the many projects undertaken by our members around the world.

While our member companies each have their own best practices, it can only strengthen our sector, and in particular to show the world our commitment to creating sustainable infrastructure, to have a dreading industry set of standards.

The *Sand as a resource* paper falls under IADC's strategy for Dredging for Sustainable Infrastructure. Part of this strategy plan is to disseminate the content of the book, by the same name, in a new format. There is work in the pipeline on a new magazine that will engage readers with the ideas, techniques and best practices of planning, designing, executing and maintaining water infrastructure projects. But more on that to come next year.

In the meantime, this issue of *Terra et Aqua* includes the winner of the 2023 IADC Safety Award that was presented to Boskalis for its new water box design that eliminates the risk of implosion. Used in many projects around the world, this type of water box is currently being used by Boskalis on the Manila International Airport project. We also explore the complex and challenging project to modernise the Świnoujście – Szczecin Fairway in Poland, which involved an extensive undertaking to clear UXOs from the work site. And on page 6, we share a recent numerical study on a jet pump by Delft University of Technology.

Frank Verhoeven
President, IADC



STUDY OF SLURRY TRANSPORT CHARACTERISTICS IN A JET PUMP

In this study, the computational fluid dynamics (CFD) analysis method was used to simulate the mixing and transportation characteristics of water and mud in a jet pump. By observing the fluid mixing law in the mixing chamber, throat and other structures, the internal flow field distribution of the jet pump under different working conditions was compared and studied. As a result, the internal flow details and operation performance curves of a certain size jet mud pump were obtained. It provides theoretical support for the optimisation design of a slurry jet pump in dredging engineering.

A jet pump is a kind of fluid machinery with a simple structure. It pumps and transports another low-speed fluid with high-speed mainstream, which is widely used in various industries. In this study, the three-dimensional numerical simulation method is used to analyse the mixed transportation of mud and water in liquid-solid jet pump. Based on the idea of control variables, the flow ratio of working conditions and the length of mixing chamber of size were explored respectively and the characteristics of internal flow field were analysed. The results showed that the pressure ratio (the difference between inlet pressure and suction pressure divided by the difference between outlet pressure and suction pressure) in the flow field at the axis, generally decreased with the increase of flow ratio (the ratio of suction flow to inlet flow). The efficiency of the jet pump increases first and then decreases. Using this rule, the pressure ratio can be increased by appropriately extending the length of the mixing chamber, so as to broaden the available efficiency. The results show that when the mixing chamber length is $2.5D_n \sim 4.0D_n$, the efficient area is flat and wide, and when $l = 3.5D_n$, the liquid-solid jet pump has the best performance, the maximum pump efficiency can reach 41.4% and the corresponding optimal flow ratio is $m = 5.29$.

Numerical simulation

Multiphase model

The mixture model simulates multiphase flow by solving the momentum, continuity and energy equations of the mixture, the volume fraction equation of the second phase and the algebraic expression of the relative velocity. For each phase fluid with different velocities, it can be used to simulate multiphase fluid with very strong coupling. According to the working condition of jet pump in this article, there is mud flow in the fluid and there is relative velocity between the two phases, so it is more appropriate to select the mixture multiphase flow model for simulation calculation.

Governing equations and turbulence models

The mixture model is selected to simulate the two-phase jet pump to establish the control equation of the liquid-solid two-phase in the jet slurry pump, so as to study the incompressibility of the two-phase. The fluid mixing process mainly solves the continuity equation, momentum equation and energy equation (Lucas et al., 2014).

The continuity equation of the mixture is:

$$\frac{\partial}{\partial t}(\rho_m)+\nabla\cdot(\rho_m\vec{v}_m)=0 \quad (1)$$

Where v_m is the average mass velocity and ρ_m is the mixture density.

The momentum equation of the mixture is:

$$\frac{\partial}{\partial t}(\rho\vec{v})+\nabla\cdot(\rho\vec{v}\vec{v})=-\nabla p+\nabla\cdot(\bar{\bar{\tau}})+\rho\vec{g}+\vec{F} \quad (2)$$

Where p is static pressure, $\bar{\bar{\tau}}$ is stress tensor, $\rho\vec{g}$ and $\vec{F}$ are gravity and external force respectively. At the same time, $\vec{F}$ also contains other source terms related to the model.

The energy equation of the mixture is:

$$\frac{\partial(\rho E)}{\partial t}+\nabla\cdot[\vec{u}(\rho E+p)]=\nabla\cdot\left[k_{eff}\nabla T-\sum_j h_j J_j+\left(\tau_{eff}\cdot\vec{u}\right)\right]+S_h \quad (3)$$

In the formula, E is the total energy (J/kg) of the fluid micro cluster, including the sum of internal energy, kinetic energy and potential energy, $E=h-\frac{p}{\rho}+\frac{u^2}{2}$, h , h is the enthalpy (J/kg), h_j is the enthalpy (J/kg) of component j, defined as $h_j=\int_{T_{ref}}^{T}C_{p,j}dT$, where $T_{ref}=298.15K$; k_{eff} is the effective thermal conductivity (w/(m · K)), $k_{eff}=k+k_t$, k_t are the turbulent thermal conductivity, determined according to the turbulence model used, J_j is the diffusion flux of component j; S_h is the volume heat source item including chemical reaction heat and other user-defined heat sources.

The turbulence model uses the most widely used standard $k-\varepsilon$ model (Desevaux et al., 2002), its turbulent kinetic energy k and its dissipation rate ε. It can be obtained from the following transport equation:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\varepsilon-Y_M+S_k \quad (4)$$

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial x_i}(\rho\varepsilon u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right]+C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}+S_\varepsilon \quad (5)$$

Where G_k is the turbulent kinetic energy due to the average velocity gradient, G_b is the turbulent kinetic energy due to buoyancy, Y_M is the contribution of fluctuating expansion to the total dissipation rate in compressible turbulence, $C_{1\varepsilon}$, $C_{2\varepsilon}$ and $C_{3\varepsilon}$ are constants, σ_k and σ_ε are Turbulent Prandtl numbers for *K and* ε respectively. S_k and S_ε is a user-defined source term.

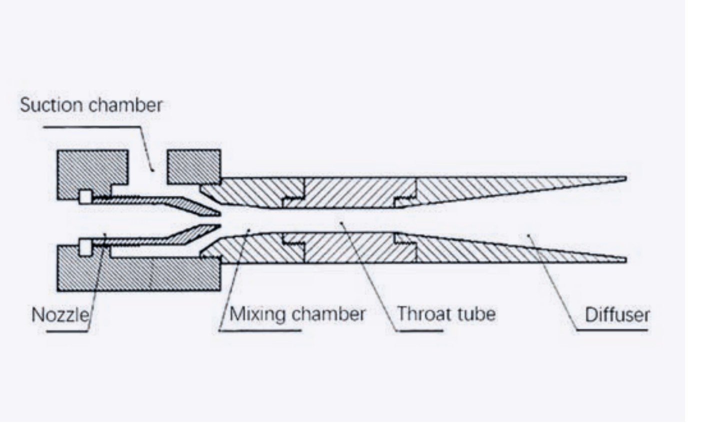


FIGURE 1

Jet pump structure diagram.

Establishment of numerical model

Basic structure and parameters of jet pump

A typical jet pump is generally composed of five parts: nozzle, suction chamber, mixing chamber, throat and diffuser. The specific structure is shown in Figure 1.

Multiphase model

Each part is responsible for the corresponding specific functions, which are connected and cooperated with each other to complete the ejecting and conveying function of the jet pump. In addition to the different working environment, some operating characteristics of the jet mud pump are the same as those of the ordinary single-phase jet pump, and its efficiency still depends on several main parameters in the jet pump theory. The main parameters that have a great impact on its performance are the size and structure of the pump itself, the working flow and pressure of the pump. Because jet pumps are widely used, their sizes and working conditions vary in different environments and there is no one jet pump structure suitable for all, so there is no standardization of specifications (Mallela et al., 2011). In general, dimensionless parameters are mostly used for analysis in the research process. The important dimensional parameters and performance indicators in the research work are listed below:

$$m=\frac{S_t}{S_n} \quad (6)$$

$$M=\frac{Q_s}{Q_o} \quad (7)$$

$$H=\frac{P_e-P_s}{P_o-P_s} \quad (8)$$

$$\eta=\frac{MH}{1-H} \quad (9)$$

Including the area ratio m, flow ratio M, pressure ratio H and efficiency of the jet pump η. Subscripts respectively represent: s is the suction chamber, o is the nozzle inlet, n is the nozzle outlet, t is the throat and e is the pump outlet.

Nozzle Inlet D_i(mm)	Nozzle Inlet Angle α(°)	Nozzle Outlet Diameter D_n(mm)	Mixing Chamber Length L(mm)	Throat Diameter D_t (mm)	Mixing Tube Length L_t (mm)	Angle of Diffuser Inlet α β(a°)	Diffuser Length L_d (mm)	Area Ratio m
16	13.8	8	8	32	192	8	180	16

TABLE 1

Geometric parameters of jet pump.

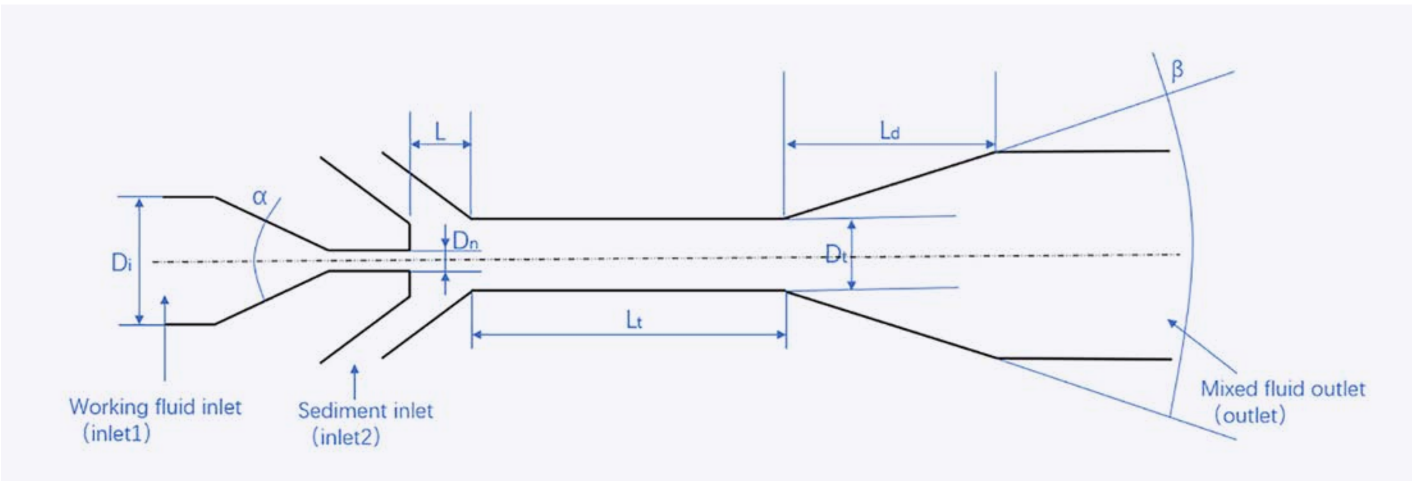


FIGURE 2

Principle and boundary conditions of jet pump.

Modelling of jet pump

According to the working requirements of the solid-liquid jet pump and the literature (Maosen et al., 2014; Giacomelli et al., 2019), the suction section of the ejector fluid is simplified to be parallel to the axis line of the nozzle and the conical straight nozzle is selected. The principle and boundary conditions of the jet pump are shown in Figure 2. The main geometric parameters are shown in Table 1.

Mesh generation of 3D model

In order to ensure the calculation accuracy and improve the calculation speed, this study uses ICEM CFD to process the structured hexahedron grid of the calculation domain model and appropriately extend the jet pump outlet length, and locally densify the area with large pressure and velocity gradient (nozzle outlet, mixing chamber and throat upstream) (Ariafar et al., 2015). In the parts where the numerical transfer connection is relatively gentle, such as the fluid inlet and outlet and the downstream of the throat, loose grids are divided. This can not only reduce the number of discrete nodes and

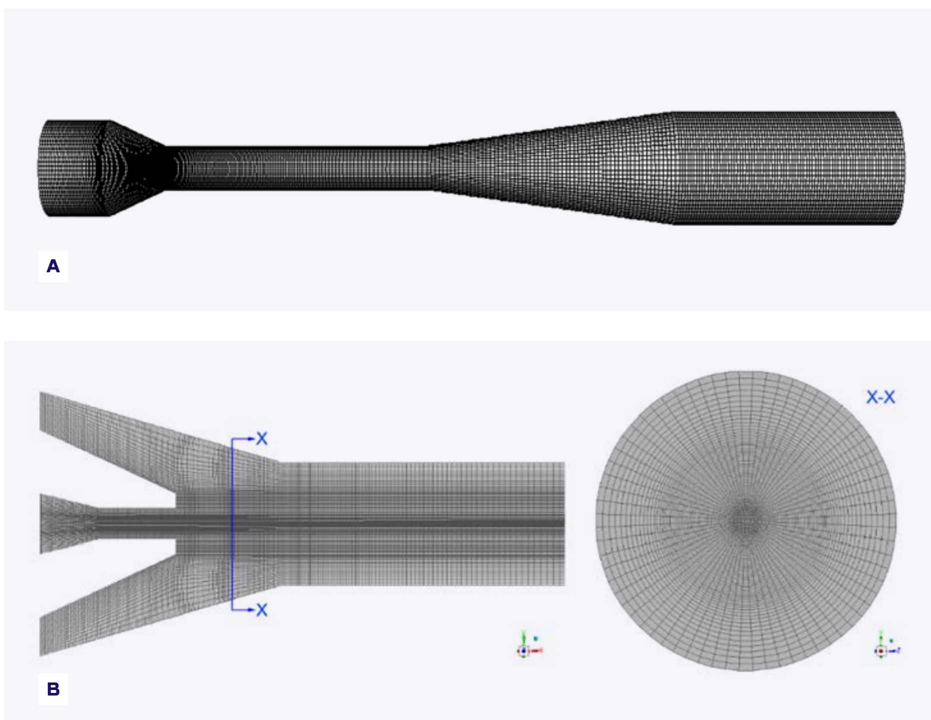


FIGURE 3A & 3B

Mesh generation and local encryption in computational domain.

Number of grid nodes	637845	883452	1030459	1327280	1548932	1762390
Outlet pressure p_e (pa)	-119145	-149350	-164324	-176020	-176002	-176045

TABLE 2

Outlet pressure of jet pump with different number of grid nodes.

speed up the calculation process, but also reflect the distribution of the internal flow field of the liquid-solid jet pump more truly and improve the efficiency of numerical simulation.

Boundary condition

The working fluid medium is liquid water, the injected fluid slurry is a 20% volume fraction of sand water mixture and the density of sand is 2.65 kg/m3. The mixture model is used to solve the two-phase flow. The boundary conditions of working fluid are velocity inlet, secondary flow slurry is velocity inlet and pump outlet is free flow. The independent variable M is changed by changing the flow of two-phase water and mud. The simple algorithm is selected to solve the coupling of velocity and pressure, and the first-order upwind scheme is used to reduce the influence of false dissipation. The time step is set to 5 × 10-4. The residual error of each calculation condition is less than 10-4 and the relative error is less than 0.5%.

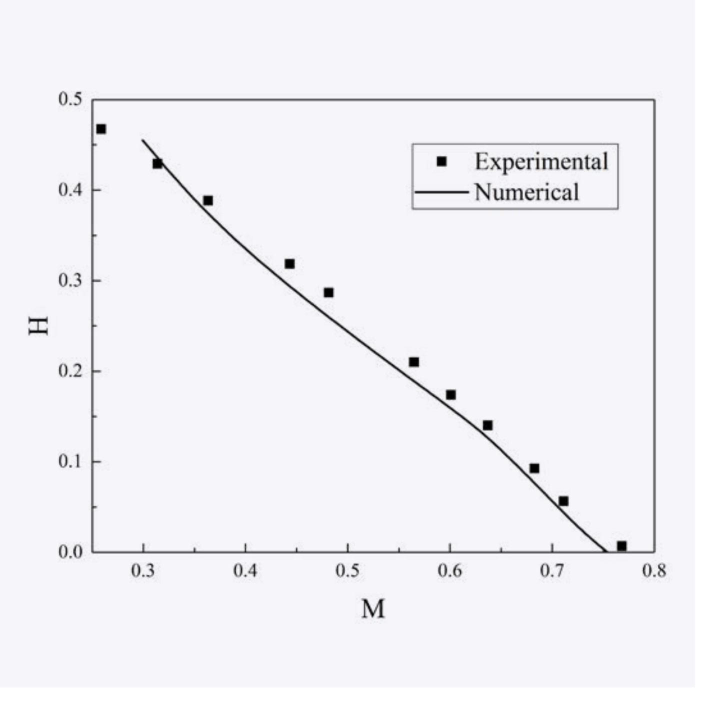


FIGURE 4

Comparison of literature experimental values and CFD simulation values.

Grid independence verification

In this study, taking the model outlet pressure P_e as the reference value, the same model was discretised with different degrees of density and then the same boundary condition value was used for calculation (the model with 1D mixing chamber length was selected). It can be seen from the data in the table that when the number of grids increases to 1327280, the outlet pressure will no longer decrease significantly and the flow field simulation solution is basically stable and reliable. In order to save the computational cost, the grid processing of all models in this study is about 1.32 million grids.

Numerical simulation verification

This study verifies the reliability of the simulation results by comparing the numerical simulation results with the performance curve data obtained by Yu et al. (Jianliang et al., 2001) from the experimental study of liquid and liquid gas jet pumps. Selecting the jet pump size with the area ratio m = 1.92, the secondary flow void fraction in the literature was analysed β = 0 is the working condition of liquid ejecting liquid. The relationship between the dimensionless parameter H-M is shown in Figure 4. The trend of the simulated value and the experimental value is consistent. At the same time, the data are basically in good agreement and the errors are within 8%, which meets the allowable range in theory. Therefore, it is considered that the numerical simulation result is reliable.

Numerical analysis of flow field in jet pump

Flow field analysis of jet pump axis

Pressure distribution

Figure 5 shows the pressure nephogram of the liquid-solid jet pump along the axis. By analysing the pressure nephogram, it can be seen that the liquid-solid jet pump presents negative pressure distribution from the nozzle outlet to the mixed fluid outlet and the pressure gradually rises along the flow direction. With the increase of flow ratio m, the minimum negative pressure gradually extends from the mixing chamber to the whole throat along the axial direction and the pressure fluctuation area in the throat is stable.

The pressure in the jet pump is negative pressure. Figure 6 shows the absolute value distribution of the pressure at the axial line in the jet pump. The working fluid enters the mixing chamber and the pressure decreases in a cliff like manner at the tapered pipe. This is because the convergence angle between the high-speed working fluid and the low-speed slurry causes a large amount of energy loss, so the working fluid pressure can be converted into kinetic energy, and the negative pressure in the suction chamber is ensured to achieve the normal suction of slurry. After that, with the gradual mixing of two-phase flow, the pressure increases slowly. It is worth noting that under the condition of small flow ratio, the

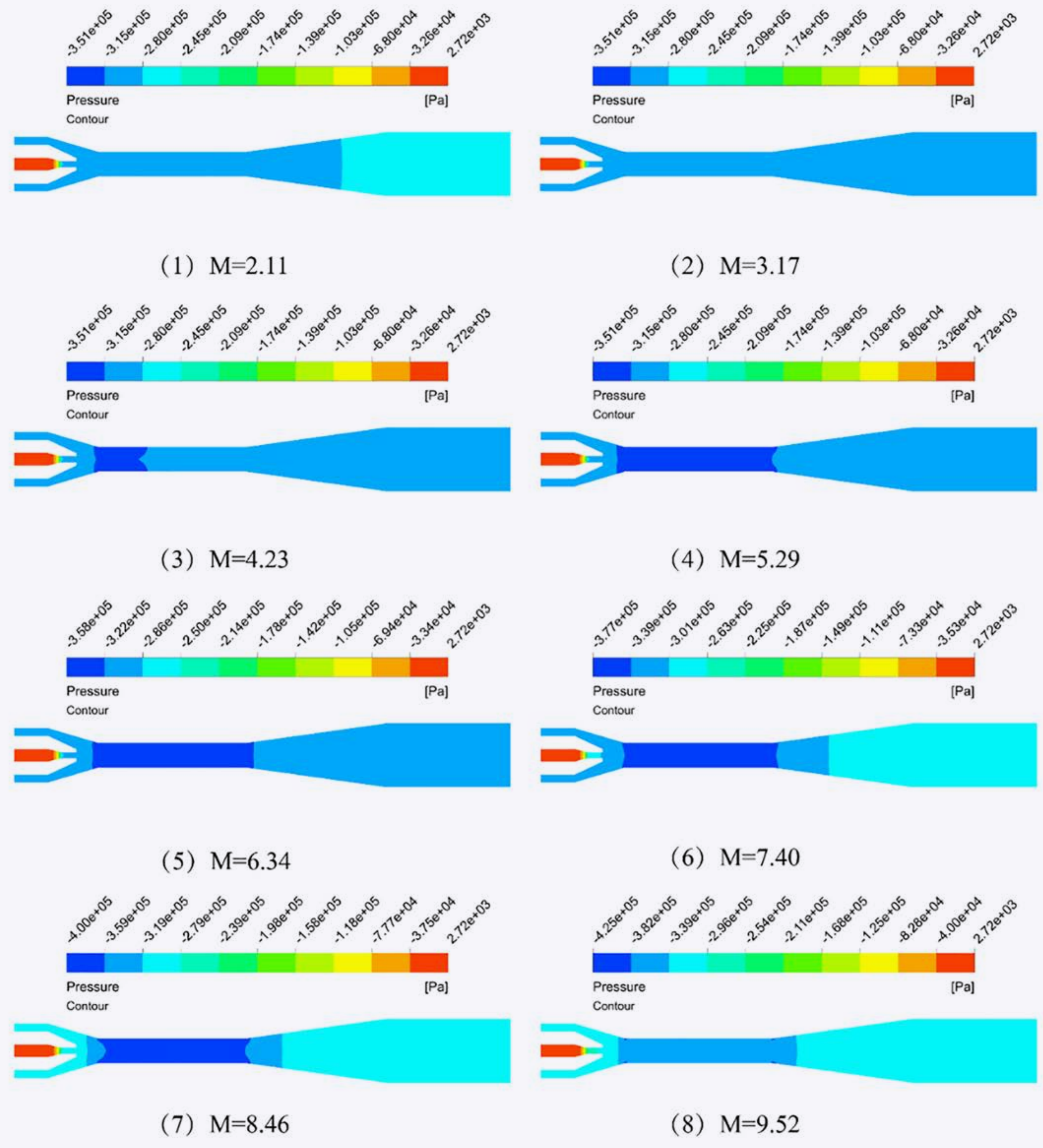


FIGURE 5

Axial pressure nephogram.

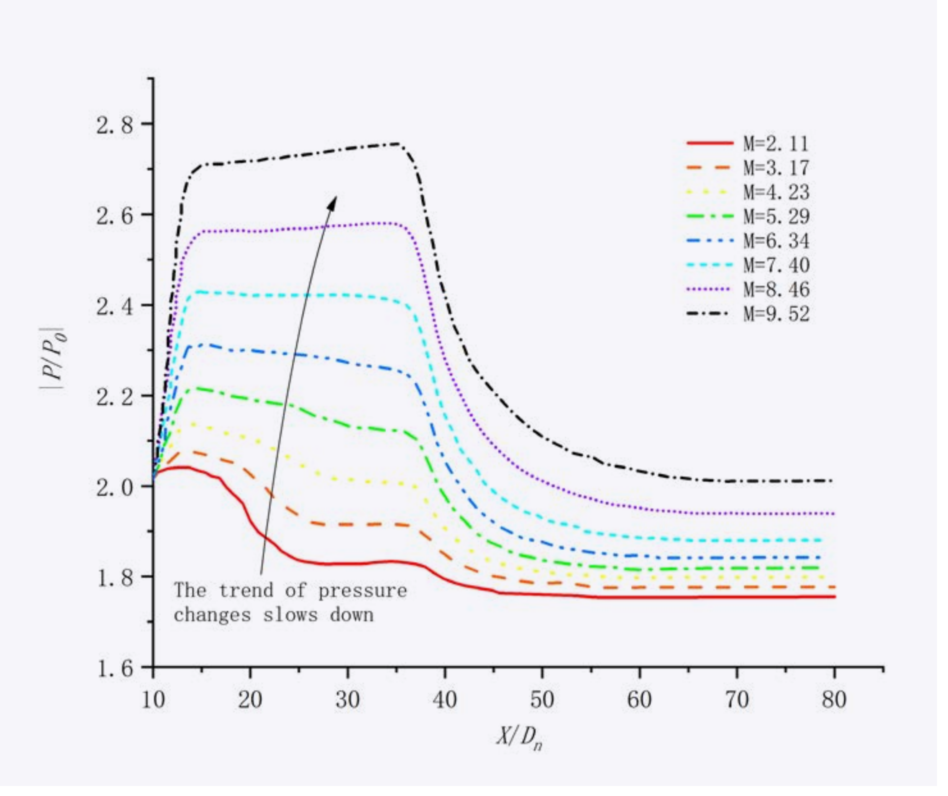


FIGURE 6

Axial pressure distribution curve in jet pump.

When the flow ratio is large, the mud flow rate increased even faster, thus losing more kinetic energy.

pressure increase trend is more obvious, and the main increase region is located at the downstream of the mixing chamber. When M = 7.40, the minimum negative pressure P = 2.5 × 10-5pa, the negative pressure of the suction chamber was further strengthened and the suction performance of the mud was optimised, but at the same time, the pressure in the throat became abnormally slow and tended to the contour line. After the M value exceeded 7.40, the pressure from the throat inlet to the diffuser inlet would change from rising to falling. The reason was that when the flow ratio was too large, the mud flow rate increased faster thus losing more kinetic energy during the mixing process, resulting in a continuous decrease in pressure (Xinping et al., 2012). As a result, the mixing section of two-phase flow increases and the mixing effect becomes worse.

Velocity distribution

The velocity nephogram of the central axis of the mixture is analysed as shown in Figure 7. It is obvious that the most direct impact of the increase in flow ratio is reflected in the velocity distribution of the mud suction inlet and the fluid near the wall. When the flow ratio is low and the upstream wall of the lower throat is low, the flow rate has reached a medium value of 8.36 m/s at the throat and even the wall at the inlet of the mixing chamber, reflecting the radial expansion of the high-velocity region. At the same time, along the flow direction, it can be observed that the high velocity region gradually expands in the axial direction. The boundary layer at the end of the high-speed flow region mainly appears at the tail of the throat under low flow rate conditions. Under high flow rate conditions, it gradually appears in the middle and tail of the diffuser. Correspondingly, the flow velocity core also continues to grow and experiences delayed attenuation. This will make the effective distance of viscous friction of two-phase fluid longer and fully exchange momentum, which is conducive to the acceleration of the injected mud.

Figure 8 shows the velocity distribution at the axial line in the jet pump. After entering the nozzle, the fluid undergoes energy conversion. The velocity rises sharply and then flows out from the nozzle outlet. In the front of the mixing chamber and throat, its velocity maintains for a period of time. After that, as the two-phase flow is mixed in the throat, the velocity decreases significantly. After reaching the diffuser, the velocity energy of the mixed fluid is converted into pressure energy. The speed is further reduced to the stable flow rate at the outlet.

With the increase of secondary velocity, the kinetic energy of the mixing of the two fluids is greater. We observed the decreasing trend of velocity at the throat outlet and inside the diffuser. We found that under various operating conditions, the speed reduction caused by energy conversion in the diffuser is much more significant than that at the throat outlet. Especially when the flow rate is small, such as M=2.11 and M=3.17, the velocity of the throat outlet section has approached a horizontal trend. If the speed at the outlet section is only affected by the deceleration effect in the

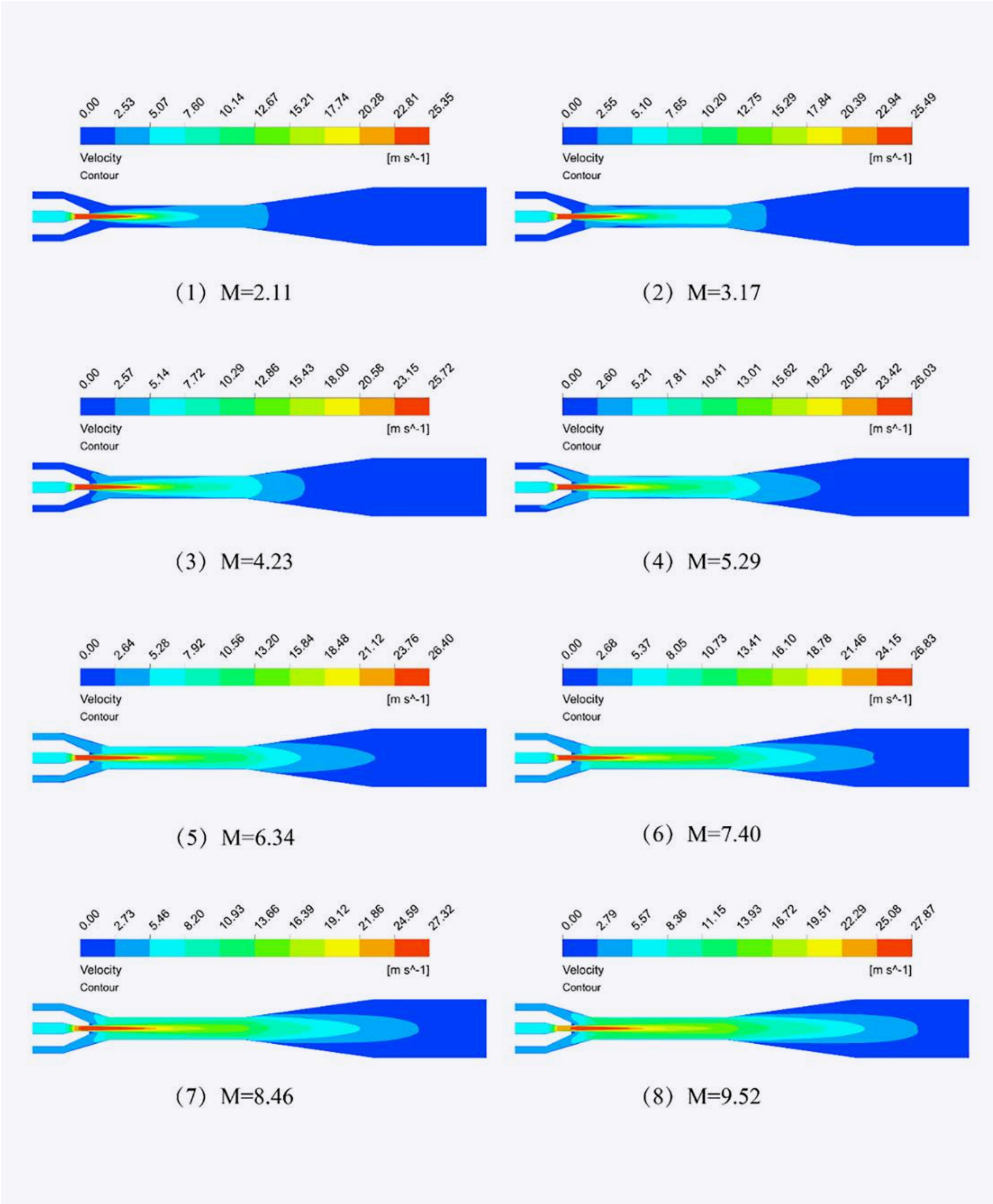


FIGURE 7

Velocity nephogram of middle axis.

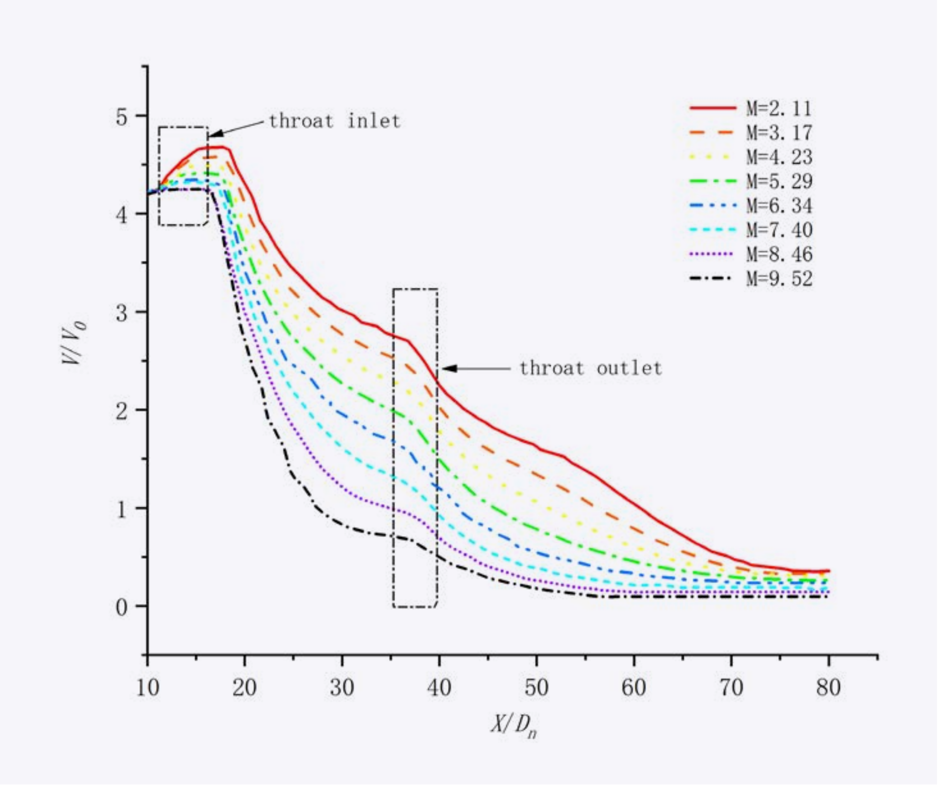


FIGURE 8

Axial velocity distribution curve in jet pump.

With the increase of flow ratio, the absolute pressure curve of the mud from the mixing chamber to the outlet section is rising. This means that the mud pressure in this part is declining, mainly because the mud has a wider range of velocity and pressure fluctuations (Wu et al., 2018) under high-flow ratio, resulting in more energy loss in the mixing process.

In addition, we compared the pressure distribution of the outlet straight pipe section. We found that, except for the curve with M=9.52, the stable outlet pressure Pe of the mud after passing through the diffuser has increased compared to the initial pressure P0. This is because the mud fills pressure energy from the jet and liquid-solid jet pump structure through processes such as energy exchange, mixing, and diffusion. The development of mixed fluid is relatively stable. However, when M = 9.52, Pe < P0 indicates that the mud pressure has been declining. The reason may be that the mud has not been developed in the jet pump. The large speed and flow make it difficult to obtain energy from the working fluid, and it is constantly lost and consumed along the way. At this time, the mud cannot meet the requirements and conditions of transportation.

The pressure loss mainly comes from the shear friction between mud and wall.

throat, a longer throat length is required. Blindly increasing the throat length is bound to bring more flow losses; as an energy conversion device, the diffuser can bring effective speed reduction, which also proves the necessity of the existence of diffusion section.

Mud flow state

Mud pressure change

The pressure distribution of the mud is negative pressure distribution, and the pressure at the mud suction port is P1. The absolute value pressure distribution curve of the mud is shown in Figure 9. The analysis of the whole injection process of mud shows that the pressure loss of mud mainly comes from the shear friction between mud and wall. Due to the negative pressure generated by the high-speed working fluid, the mud pressure in the suction chamber is greatly reduced. After that, the mud and working fluid are gradually mixed in the throat, and the pressure gradually rises steadily. Then, after being diffused by the diffuser, it reaches the straight pipe section at the outlet and the mud reaches a stable pressure higher than the suction port. It is then discharged from the jet pump.

Mud velocity change

The wall velocity distribution of slurry from nozzle inlet to outlet is shown in Figure 10. Observe that there is no significant difference in the variation trend of mud velocity at each flow ratio from the suction port to the mixing chamber: the mud velocity decreases through the front wall loss, and then contacts with the high-speed working fluid after entering the mixing chamber, accelerating rapidly to the first peak. The difference caused by the flow ratio is mainly reflected in the throat to the outlet section. Due to the distribution law of turbulent kinetic energy in the throat, the mud slows down first and then accelerates, so there is a minimum value of mud velocity in the throat, which gradually increases with the increase of flow ratio and moves downstream of the throat along the jet direction. When M = 7.40 is taken for analysis, the lowest velocity v = 6.33 m/s in the mud throat appears in the middle and lower reaches of the throat, leaving basically sufficient space for the accelerated development of mixed fluid. Then the mud reaches the second peak value v = 7.60 m/s. At this time, the phase velocity difference between the two fluids is small, the fluctuation is gentle, and the disturbance to the mixed fluid about to enter the diffuser is small.

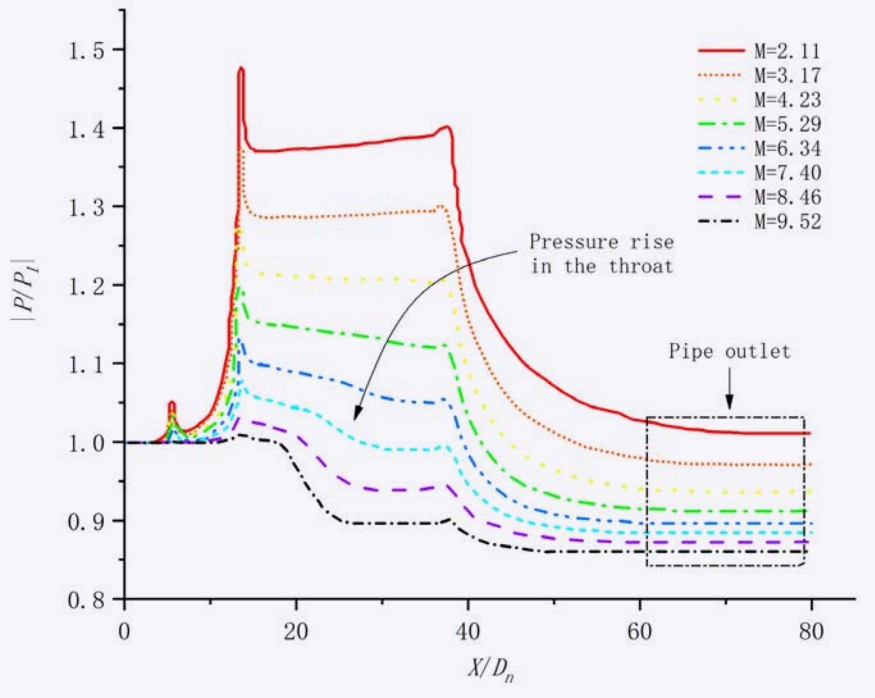


FIGURE 9

Mud pressure distribution curve.

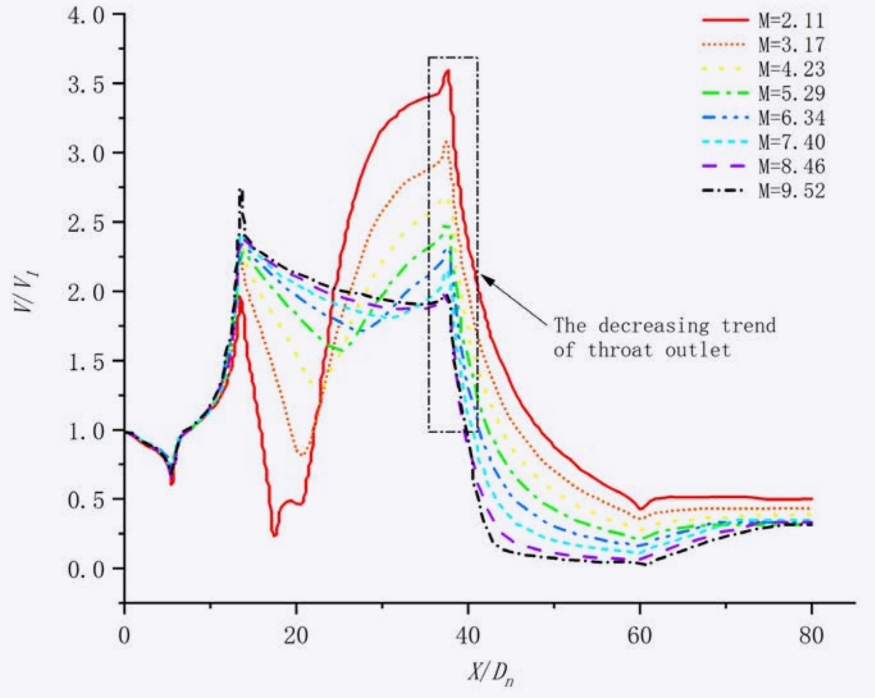


FIGURE 10

Mud velocity distribution curve.

Overall performance analysis of liquid solid jet pump

Pressure ratio H

Pressure ratio H is one of the important dimensionless parameters of liquid-solid jet pump, which is expressed as the ratio of the pressure difference between the inlet and outlet of mud and the pressure difference between the inlet and outlet of working fluid. The value of H can be used to reflect the working condition of liquid-solid jet pump. The curve relationship between the pressure ratio H and the flow ratio M of the liquid-solid jet pump is drawn as shown in Figure 11. It shows that the pressure ratio of the liquid-solid jet pump is continuously decreasing with the increase of the flow ratio (due to the relatively faster increase of the velocity of the injected mud in the two-phase flow at a large flow ratio), and more suction friction losses in the suction pipe section and the mixing chamber section. With the increase of mixing chamber length L, the pressure ratio curve moves upward, which is more obvious in the high-flow ratio section. Therefore, increasing the mixing chamber length within a certain range can effectively improve the pressure ratio in the high flow section and promote the mixing of liquid-solid two-phase flow. At the same time, reference (Zhiyue, 2008) shows that there is an approximate parabolic mathematical relationship between the pressure ratio and the flow ratio. In this article, the simulation value of l = 3.5Dn is selected for fitting and the function of H on M is obtained.

The conclusion of this formula can be used for the rough calculation of liquid-solid jet pump selection and has certain reference significance for the specific jet pump with pressure ratio (head ratio).

Efficiency

It is found that the mixing chamber length L and the injection flow ratio m have key effects on the performance of the liquid-solid jet pump in different simulation processes of injecting mud. The efficiency curves under different mixing chamber lengths and flow ratios are shown in Figure 12. With the increase of the flow ratio, the efficiency curve shows a parabolic trend, and = 0 is the boundary, with efficiency peak and negative efficiency region. Due to the absence of moving parts and low energy conversion rate, the overall efficiency of the liquid-solid jet pump is less than 45%, but there is an efficient working condition that can be achieved by adjusting the flow ratio. With the increase of mixing chamber length, the efficiency curve of jet pump gradually moves upward and the change of low flow ratio region is small. However, the curve of high-flow ratio region obviously continues to rise and the overall trend becomes wider, which makes the high-efficiency region wider and means that the adjustable flow ratio is reached. As the further increase of the mixing chamber length will increase the length of the wall and channel, and the friction loss between two-phase flow and between the outer fluid and the solid wall will be more serious, the mixing chamber has an optimal length. For that reason, L = 3.5Dn is selected in this study. At this time, the efficiency curve is relatively wide and the maximum efficiency value is about 40%. However, once the flow ratio is too large, the liquid-solid jet pump will have a negative

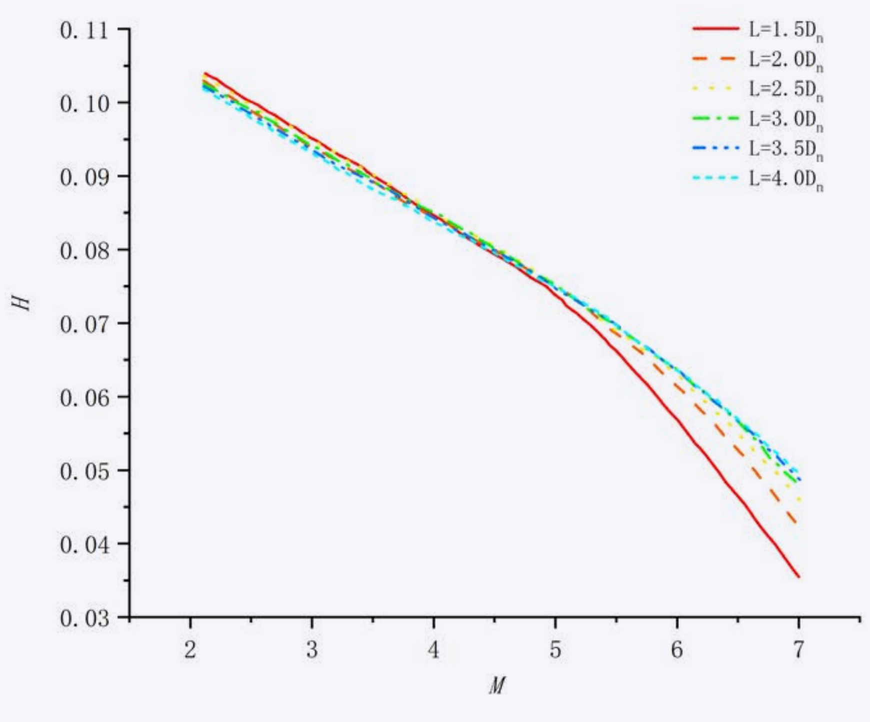


FIGURE 11

Pressure ratio H-flow ratio M curve of jet pump under different mixing chamber length.

efficiency suction area (Yang, 2018), mainly due to the high mud flow rate when the flow ratio is too large, and will even replace the working fluid as the mainstream. A large amount of momentum is lost in the process of two-phase flow injection mixing and the conveying efficiency is negative.

Conclusions

This article uses CFD method to numerically simulate liquid-solid jet pumps operating under different structural parameters and conveying conditions, comprehensively analysing their internal flow field characteristics and obtaining the following conclusions:

1. The jet pressure and velocity distribution at the axis line of the liquid-solid jet pump show regular changes with the increase of the flow ratio. The suction negative pressure in the throat depends on the flow ratio. The higher the flow ratio, the lower the minimum pressure in the jet pump; the flow ratio also determines the upward trend of the pressure in the throat. With the increase of the flow ratio, the upward trend of the pressure curve obviously slows down and even continues to decrease under a large flow ratio. In terms of axial velocity distribution, the increase of flow ratio leads to the increase of the overall axial velocity, while the peak value of velocity increases continuously, which prolongs the velocity core and delays the attenuation.
2. As the ejected fluid, mud is an important conveying object and its specific working condition flow pattern analysis is also of great significance for understanding and improving the work of jet pump. The mud pressure distribution is similar to the axial pressure curve, which verifies the axial distribution law of pressure; the pressure of the straight pipe section at the outlet is generally higher than the pressure at the mud suction inlet. With the increase of the flow ratio, the pressure continues to decrease until the outlet pressure is lower than the suction pressure and the mud transportation does not meet the working requirements. The mud flow rate has a deceleration stage in the two lifting stages, so that there is a minimum velocity in the throat, which affects the overall distribution of mud velocity and can be adjusted by changing the flow ratio. With the increase of flow rate ratio, the core of mud injection is expanded and the distribution of acceleration region is expanded along the radial direction.
3. The pressure ratio and efficiency of two-phase flow are used as indicators to measure the overall performance of liquid-solid jet pump. It is found that both are greatly affected by the length of mixing chamber and flow ratio. The pressure ratio decreases with the increase of flow ratio and the pressure ratio can be effectively improved by increasing the length of mixing chamber. The efficiency of the jet pump first increases and then decreases with the increase of the flow ratio and the appropriate length of the mixing chamber can broaden and improve the high-efficiency area. It is found that when l = 3.5Dn, the liquid-solid jet pump has the best comprehensive performance with a wide range of operable flow ratio (5.29, 6.40) and the maximum pump efficiency can reach 41.4%.

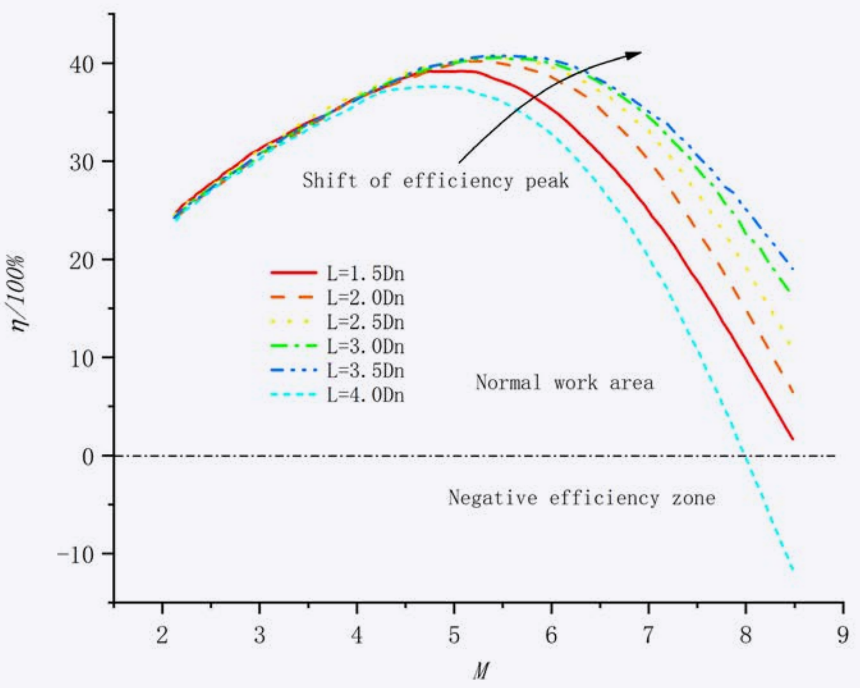


FIGURE 12

Efficiency flow ratio curves under different mixing chamber lengths.

Summary

This study combines the challenges of mud transportation in the dredging industry and applies jet pumps to liquid-solid transportation. CFD methods are used to numerically simulate the flow process and details of liquid-solid jet pumps operating under different structural parameters and conveying conditions. The results show that the jet pump has experienced rapid jet attenuation, strong pressure attenuation at the throat and limited effective operating range.

The efficiency of liquid-solid jet pumps is constrained by various factors, among which the flow ratio and mixing chamber length studied in this article have a significant impact. Under the premise of appropriately increasing the mixing chamber length, the efficient area of the jet pump can be effectively widened and improved. At the same time, according to the characteristics of the quadratic curve law, targeted experiments can be conducted to select the optimal flow ratio of the jet pump, which can enable the liquid-solid jet pump to operate at the best comprehensive performance and improve work efficiency. This article explores the influence of flow ratio and mixing chamber length on the liquid-solid jet pump and proposes a method to obtain the optimal comprehensive performance, providing reference for engineering practice.

Due to insufficient research on jet mud pumps, this article designs and analyses a specific structural model. Jet pump injection of fluid is a relatively dynamic process and in future work, the influence of structural parameters and different slurry concentrations can be considered. Further study of the transient process of internal jet will gain a more comprehensive understanding of the flow field characteristics of liquid-solid jet pumps.

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Xiuhan is a research scientist working for the Offshore and Dredging Engineering department of Delft University of Technology in the Netherlands. He specialises in seabed processes and digital twin modelling for dredging. In his PhD, he built a framework of numerical models that simulates the underwater excavation process. Xiuhan is actively involved in both CEDA and WODA, and is the General Secretary of WODA Technical Orientation Committee and Reservoir Dredging Working Group.

Sape Miedema

In June 2022, Sape retired as Associate Professor from Delft University of Technology (TU Delft) after a 42-year career in dredging engineering. From his student days at TU Delft, obtaining both his MSc. in Mechanical Engineering and his PhD, he went on to become educational director of Mechanical Engineering and Marine Technology in conjunction with his associate professorship of Dredging Engineering. For the past 15 years, Sape's focus has been on his role as director of studies of TU Delft's MSc Marine Technology programme and on writing scientific papers. He is the author of 157 technical papers, journal entries and books, 57 reports and the recipient of 16 prestigious awards for his research into a universe of dredging and transport methods. While enjoying his retirement, Sape continues to work for his consultancy company, SAM Consult.

References

Ariafar K., Buttsworth D., Al-Doori G. and Malpress R. (2015)
Effect of mixing on the performance of wet steam ejectors. Energy, 93.

Desevaux P. and Aeschbacher O. (2002)
Numerical and experimental flow visualisation of the mixing process inside an induced air ejector. *International Journal of Turbo and Jet Engines*, 19, 71-78.

Giacomelli F., Mazzelli F., Banasiak K., Hafner A. and Milazzo A. (2019)
Experimental and computational analysis of a R744 flashing ejector. *International Journal of Refrigeration*, 107.

Jianliang Y., Xuehua G. and Xiaoshi H. (2001)
Experimental study on liquid liquid gas jet pump. *Chemical industry and engineering*, (02): 103-108.

Lucas C., Rusche H., Schroeder A. and Koehler J. (2014)
Numerical investigation of a two-phase CO2 ejector. *Internal Journal of Refrigeration*, 43, 154-166. https://doi.org/10.1016/j.ijrefrig.2014.03.003.

Mallela R. and Chatterjee D. (2011)
Numerical investigation of the effect of geometry on the performance of a jet pump. 225(7).

Maosen X., Xinping L., Xuelong Y., Wei W., Xiaochuan W. and Xueying W. (2014)
Effect of nozzle position on performance of new annular jet pump. *Journal of drainage and irrigation mechanical engineering*, 32 (07): 563-566+582.

Wu Y, Zhao H, Zhang C, Wang L, Han J. (2018)
Optimisation analysis of structure parameters of steam ejector based on CFD and orthogonal test. *Energy*, doi:10.1016/j.energy.2018.03.041.

Xinping L., Honggui C., Xuelong Y. and Longzhou X. (2012)
Performance simulation and experimental study of jet pump with super large area ratio. *Journal of drainage and irrigation mechanical engineering*, 30 (04): 379-383.

Yang L. (2018)
Study on performance of ejector for drainage gas production in low pressure gas wells. China University of Petroleum (Beijing).

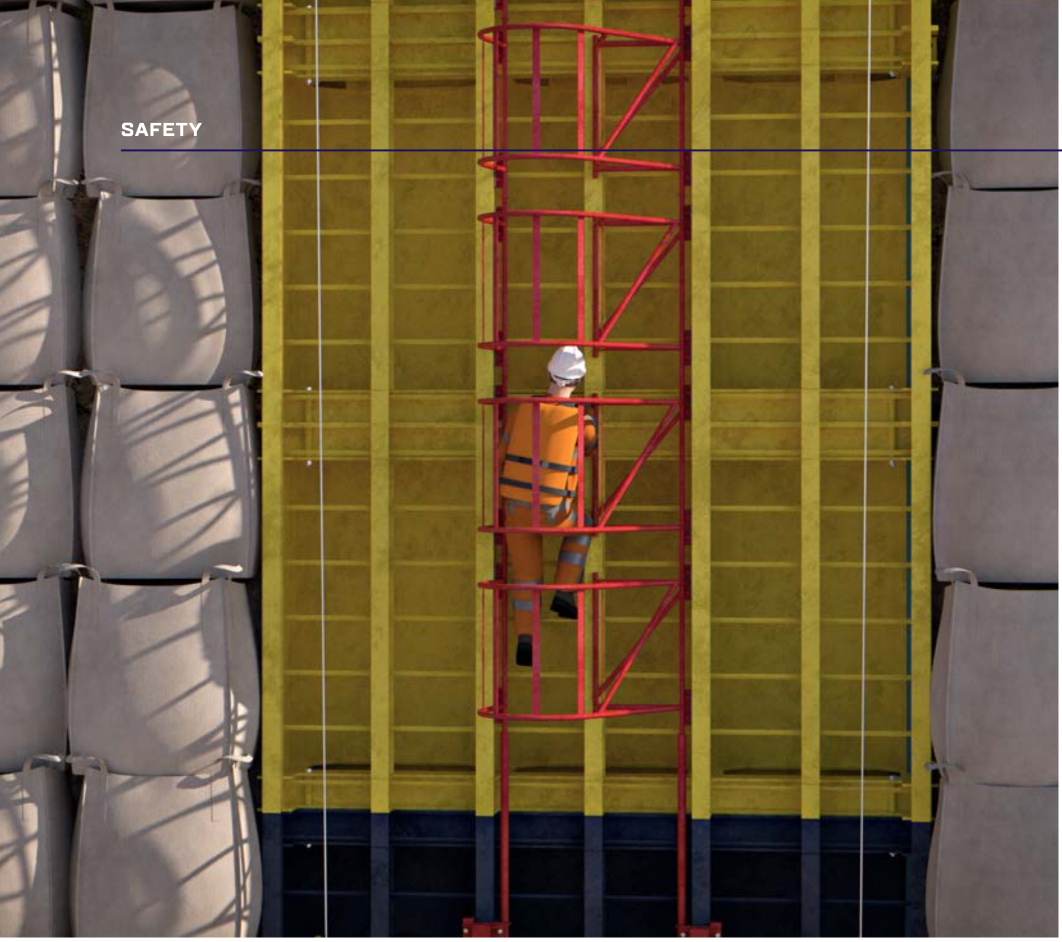
Zhiyue B. (2008)
Research on efficiency optimisation and control of dredger slurry pipeline transportation system. Zhejiang University.

BOSKALIS ELIMINATES RISK OF IMPLOSION WITH NEW DESIGN FOR WATER BOX

Alongside pumping sand, managing the water level in the landfill is an important aspect of a dredging project. A water box, a metres-high structure in which planks can be positioned manually to keep the water at the desired level, is indispensable for this work. Boskalis recently won the Safety Award of the International Association of Dredging Companies (IADC) for its new, modular and, above all, safer design that eliminates the risk of incidents.

"When we get into the water box to install the wooden planks, we never wear a life jacket." This comment from a Boskalis landfill master during a project in Australia certainly grabbed Ferry van der Hulst and Daan van de Zande's attention. Besides that, indirectly, those words from Down Under led to a radical change in the design of the water box.

Until then, the landfill crew literally climbed down into the steel structure to install the wooden planks from the inside in order to control the outflow of water into the landfill and the settling time of the dredged material.



The main hazard was that, if there was an accident – a fall from the ladder, for example – a crew member could end up in the water and, because of the strong current in the water box, only be able to escape through the pipeline through which the excess water is drained. “A life jacket keeps you on the surface, making escape impossible. Climbing back up the ladder is also impossible: the enormous turbulence caused by the incoming water means you can barely keep your head above the surface, if at all,” says Van der Hulst, project engineer for the Boskalis Central Fleet Support department. “When we heard this, we got to work on the design and came up with the idea of making it possible for people to work from outside the water box. That’s a lot safer. Because when you’re working on the outside, there’s always a way to get away safely if necessary.”

YES scan

A long calculation and design process followed at Boskalis’ head office in Papendrecht, the Netherlands. It involved not only the Central Fleet Support department but also staff from

the Research & Development department and dredging projects. "During the history of Boskalis, we have always used the water boxes as we have known them: by installing the planks from the inside. But as projects have got bigger and bigger, and after a number of incidents (and near-misses), we knew we had to change the design to make things safer for our colleagues," says Van de Zande, operations director for the cutter suction dredgers at Boskalis. "Go figure: with what we know now, working in the water box could never pass the YES scan in our own NINA (No Injuries, No Accidents) safety programme. YES stands for Yourself, Equipment and Surroundings; these three areas must be safe and checked before you can start work. With the old approach, two out of three failed to comply with the standards and values we set out in our own NINA programme."

In a nutshell, the design modification meant that, instead of going down to the water level in the landfill from the inside, personnel on the landfill can now use a safe stairway to access a manually operated platform that allows them to move up and down the outside of the water box. The planks are then put into position from that platform, which resembles those used by window cleaners on high buildings. Van de Zande: "It's actually a very simple solution that immediately makes things lots safer for our colleagues. Every dredging company in the world deserves a water box like this: it makes a direct contribution to safety on a project."

Design

However, large and impressive the water box may be from up close, the updated design is modular and so it can be used on any type of project. The water box consists of three "containers" with different colours: a blue lower box connected to the pipeline through which the water exits from the landfill, a yellow "middle box" that can be used to raise the structure and the top box in a red warning colour that is connected to the platform. "Each water box consists of at least one blue, one yellow and one red container with a maximum height of 10 metres," explains Van der Hulst. Boskalis now has 19 of the new water boxes. 15 of them are being deployed on the largest dredging project in the history of Boskalis: the Manila International Airport project in the Philippines.

Preventing implosion

The new water box was designed and produced to eliminate the risk of implosion due to soil pressure when the pressure of the soil in the landfill becomes too large for the

structure. So the new design is a lot stronger. "You can base your calculations on three types of soil pressure: active, neutral and passive. The load differs by a factor of three for each approach. Neutral soil pressure is three times as high as the passive soil pressure and the active soil pressure is three times as strong as the neutral soil pressure," says Van der Hulst. "So we decided to design the new water box to withstand active soil pressure. From practical experience, we know that the pressure on a landfill never reaches the active pressure we have now used as the theoretical basis for our calculations. So we are confident that this box is the safest there is."

Obviously, during the design process, Van der Hulst and his colleagues used the prevailing Quality Assurance and Quality Control (QA QC) requirements, which state that the quality of the structure has to be easy to measure in the long term and that the production process must be optimised. "The design meets the highest standard in terms of strength and resilience to soil pressure and, when it comes to quality, we measure the steel thickness of the water box after every operation and conduct visual inspections. This allows us to see how much wear there has been during the project and whether repairs need to be made before the box is used again," says Van der Hulst. "Working with the water box in this way allows us to eliminate risks during operations."

Practical test

Of course, a water box is not the only way our dredging colleagues can control water levels and settlement time in the landfill. Another widely used method is placing a pipeline in the dike around the landfill at a certain height so that all the water above that level is discharged through the pipeline. Another alternative is covering the dike with a tarp so that all the excess water flows over the dike naturally. Van de Zande: "These are also excellent approaches and they are also typical of the enterprising approach in the sector to manage situations in inventive ways. But our aim with the new, safer water box is that, when a project manager decides to use this method, it will be the safest option."

Support from project managers is certainly crucial for the success of the new water box, explains Van der Hulst. "I'm an engineer, a numbers man. So you need colleagues with hands-on experience to check whether an idea is the best possible option. We sometimes come up with fantastic solutions but they are useless if they don't pass muster with our colleagues on the projects. For example? We thought about whether it would be possible not to have people going down alongside the water box and to position or remove the planks automatically. That turned out to be impractical: the colleagues on the platform also have to remove the non-sandy material that always ends up in a landfill so that the water can continue to flow out. Another example is the type of material used for the planks. There were drawbacks to every alternative we proposed. But wood, which has been used for decades – or perhaps even centuries – proved to be the most effective material by far."

Many of these aspects were tested at a Boskalis yard in the Netherlands, where a special test array was set up. Project managers, landfill masters and colleagues from Research & Development, Central Fleet Support and numerous other departments met there to come up with the ultimate design. Van de Zande: "So you can honestly say that this water box was a team effort from Boskalis as a whole: a perfect example of our internal motto 'Making the difference together'. And all that after that clear moment and the comment from the landfill master in Australia."

> **The design meets the highest standard in terms of strength and resilience to soil pressure.**

On behalf of Boskalis, Pim van der Knaap, Group Director, accepts the Safety Award 2023 presented by IADC's President, Frank Verhoeven (left).


Van Oord
VOX AMALIA

MODERNISATION OF THE ŚWINOUJŚCIE – SZCZECIN FAIRWAY

The idea of a modern maritime access route from the Baltic Sea to the Port of Szczecin in Poland was already born towards the end of 20th century. Quay walls in the neighbouring Port of Police, built in the 80s, were already constructed to accommodate a depth of 12.5 metres and initial modernisation works commenced in the early 90s. On 28 September 2018 the "Modernisation of the Świnoujście – Szczecin Fairway to a depth of 12.5 m" became a reality with the signing of the design and build contract between the Maritime Office Szczecin and the DIVO consortium (Dredging International NV and Van Oord).

The fairway connects the two Polish ports of Szczecin and Świnoujście with the Baltic Sea. With its new dimension to a depth of 12.5 metres, it enables an effective marine transport of all types of goods from and to both cities and further, via well-established hinterland connections to the western part of Poland, Czech Republic and Slovakia.

The entire project area had been the location of intense fighting and bombing during the Second World War, which on its own, in order to guarantee the safe execution of the dredging works, proved to be a vast undertaking. However, despite this anticipated challenge as well as some exceptional events, such as working during a pandemic (COVID-19) and a difficult period of cold and ice, the ambitious project was completed on time and was handed over to the Maritime Office in Szczecin in the spring of 2022.

Design and engineering

The project was executed in a design and construct format, encompassing a wide array of design tasks, such as the fairway dredge design, two artificial islands with jetties, rock revetments, sheet piling, cable alterations, navigational aids and the implementation of a hydrometeo and Real Time Kinematic (RTK) system.

Design work in Poland is strictly regulated, permitting only certified designers to endorse design documentation. To handle the diverse range of design tasks and adhere to Polish design regulations, a consortium of Polish and Belgium design consultants was engaged. The design consortium together with designers of both dredging contractors worked together closely to complete the design.

The fairway remained open for other vessels during the marine works. This required special attention to ensure safe dredging operations, taking into account the dredging fleet deployed, without posing an obstruction to vessels calling at port. Nautical studies were performed, creating a framework of safe passing manoeuvres for other vessels during different dredging operations (dredging, sailing loaded and sailing empty). The nautical study along with clear communication with Vessel Traffic Services (VTS) and local pilots ensured safe vessel procedures and minimised delays in the dredging operations.

The dredged material was used to create two artificial islands, with diameters of approximately 1.25 kilometres and 1.8 kilometres respectively. In the north is a nature island with no infrastructure other than a jetty required to access the island for inspections. The southern "doughnut-shaped" island will serve as a reclamation area for future maintenance dredging on the fairway. Both artificial islands are located within the Szczecin Lagoon. The original bed level at the island locations was about -5 to -6 metres. Soil investigation campaigns revealed layers of soft soils, with thicknesses varying between 1 to 8 metres. The presence of these soft soil layers greatly influenced the design and construction of the artificial islands. A rubble mound bund with steep slopes proved to be unstable. Therefore, the design was adopted to ensure geotechnical stability of the works and optimise the volume of rock required for construction.

The first step in the island construction was the installation of the sand foundation. The elevation of the foundation layer varies from -2 to -3 metres, depending on the hydraulic loading by waves after the island's completion. The foundation layers were installed by means of a spreader pontoon and followed by a consolidation period. The duration of the consolidation period varied based on the local subsoil conditions. During the second construction step, a sand bund was created reaching above water. Once dry land was formed, Cone Penetration Tests (CPT's) were performed. Over a hundred CPT's were conducted on both artificial islands to confirm the soil models used for calculating consolidation periods and to determine the degree of consolidation of the soft soil layers. Based on the CPT data, a second consolidation period was determined for every location along the island to ensure sufficient consolidation of the soft soil layer and increase the strength, enabling a safe raising of the reclamation levels to the design levels, up to +5 metres.

The construction sequencing of both islands, determined by the geotechnical stability and associated consolidation periods, is visualised with four satellite images shown in Figures 1A-D. Figure 1A, taken in October 2020, shows the submerged sand foundation layer at both islands. On the southern island, the western sector of the island was constructed above water first, since this part of the island required the longest consolidation period between the first and second above water

FIGURE 1A-D

Artificial islands: A) October 2020; B) 2 February 2021; C) 3 April 2021; and D) 4 May 2021.

reclamation step. At the northern island, the above water operations commenced.

Figure 1B, dated February 2021, shows the first step of the above water reclamation works performed along the entire perimeter in the north. The status of the southern island remained unchanged compared to the first image. The picture shows ice covering the entire lagoon, which resulted in a short interruption of the reclamation works. Figure 1C, April 2021, shows the progress on the above water works in the south. And the fourth image (Figure 1D) shows the artificial islands at the time of hand-over to the client in May 2022.

The newly designed fairway, with its increased dimensions, resulted in interfaces with the existing shoreline at a number of locations. At most locations no infrastructure was present, enabling the design of a small land cut with natural slopes. In the southern, more built-up area of the project, a number of interfaces with existing structures occurred. At four locations, the distance to existing quay walls was too limited to apply unprotected slopes, since these would affect the stability of the existing quay walls. At two locations, the fairway slope was reinforced with a revetment and at the other two locations, a combination of underwater sheet piles and a revetment was required to ensure the stability of the existing structures without reducing the navigational depth at the quay.

Furthermore, the project's impact on the flow of water from Przekop Mielenski into Lake Dąbie needed to be minimised in order to ensure unchanged environmental conditions in Lake Dąbie.

The lake entrance is in a narrow section of the fairway, thereby eliminating the possibility for natural slopes since these would widen the lake entrance. Both headlands adjacent to the lake entrance needed to be secured. At the southern headland a revetment solution was designed. Since the width of the northern headland was too small to apply a revetment solution, a sheet pile structure was designed as a combination of a sheet pile with ground anchors and a cofferdam.

The fairway modernisation also included an upgrade of the navigational aids, requiring the need to design buoys, navigation lights on structures on land and on the banks of the fairway. In total, six monopile structures were designed within the fairway banks to support

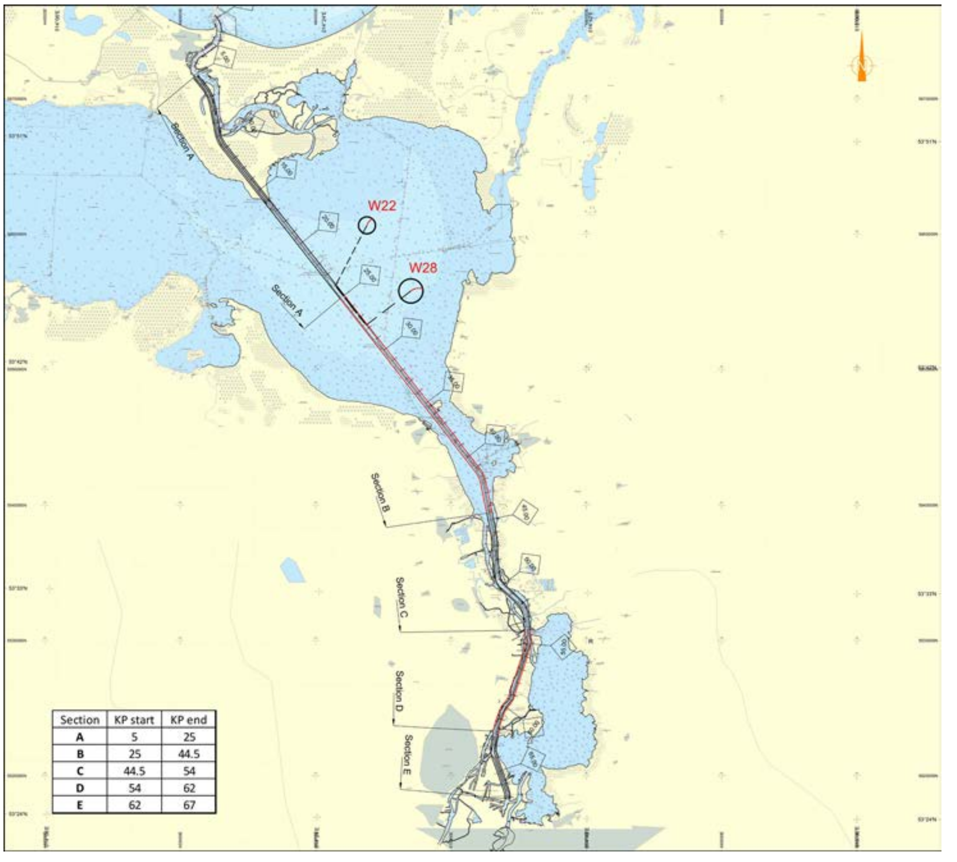


FIGURE 2

Overview of UXO removal sections in project area.

navigation lights, taking into account that winter periods with ice cover are common in the fairway. A design ice thickness of 0.35 to 0.6 metres depending on the location at the fairway proved to be the normative design load for these structures. Therefore, monopiles with a diameter of 1.0 to 1.4 metres were designed at the various locations.

Preparation works

The existing Świnoujście – Szczecin Fairway was subject to various aerial bombings, artillery, mining and other war related activities during the Second World War. Therefore, prior to the deepening and widening of the existing fairway, an extensive Unexploded Ordnance (UXO) investigation and removal campaign was executed to enable safe dredging and reclamation activities. This scope of works turned out to be a project itself within the project.

UXO investigation and removal campaign

Before actual commencement of the dredging and reclamation works, the working area had to be cleaned from hazardous objects to enable safe execution of dredging and all other marine related activities of the project. UXO presence along the existing fairway was considered a potential threat to:

- the workforce employed on board the various vessels and on the reclamation areas;
- main dredging equipment and auxiliary vessels to perform the dredging and reclamation works; and
- the marine construction works to be executed as part of the contracted project scope (i.e. cable removal and installation works, sheet and jetty piling and rock installation works).

UXO history working area

Based on historical research of the intensive war activities, the project area (with a total length over 60 kilometres) between Świnoujście and Szczecin was divided into three specific "UXO areas".

Świnoujście area

During the period between 1942 and 1945 the northern section of the existing fairway was

FIGURE 3

Aerial bombing of the German battleship "Lützow" (16 April 1945) in the existing fairway.

subject to various bombing and air defence of Świnoujście and British aerial mining of the waterways. Moreover, on 16 April 1945 the Royal Air Force executed an aerial attack on the German battleship "Lützow", stationed near Kasibor.

Within the northern part of the fairway, the UXO investigation and removal campaign focussed on the following expectations:

- High Explosive Fragmentation bombs up to 12,000 lbs;
- ground mines;
- artillery up to 300 mm; and
- munitions dumping.

Police area

Expected UXO's with the middle section of the existing fairway mainly had to do with the presence of a synthetic fuel factory, which became a target of the aerial raids. Between 1944 and 1945, repeated aerial bombing by the 8th United States Army Air Forces (USAAF) took place. Along with the bombing activities, this resulted in various planes being lost on 7 October 1944. These aerial bombing raids triggered air defence of the aforementioned factory, meaning there was potentially another source of UXO's within the project area.

FIGURE 4

Indication of crash locations of USAAF bomber airplanes.

Furthermore, throughout the period between 1942 and 1945 British forces executed aerial mining operations of the Polish waterways. Therefore, within this section of the fairway the campaign focussed on the following UXO's to be expected:

- High Explosive Fragmentation bombs up to 2,000 lbs;
- artillery shells up to 150 mm calibre; and
- ground mines.

Szczecin area

Similar to the aforementioned sections, between 1942 and 1945, the southern section of the fairway around the city of Szczecin experienced mining performed by the British Army and aerial bombing. Furthermore, artillery barrages, tactical bombing by the Soviets and amphibious assaults by the Soviet forces over the Odra river (the German and Polish name for the existing fairway) were recorded.

FIGURE 5

Aerial photo of the bombing of the refinery in Police.

FIGURE 6 & 7

Aerial photos of the bombardments Police. Source: NARA, Record Group 341, Entry 217, Box 580: Military Intelligence Photographic Interpretation Report 21325.

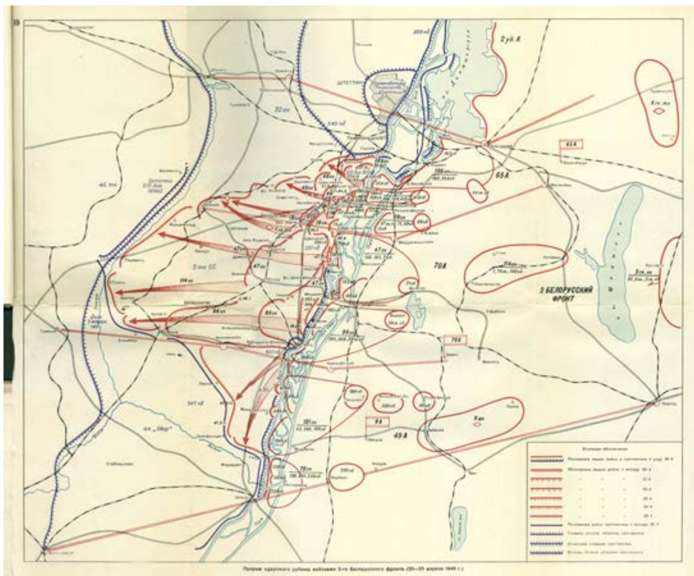


FIGURE 8

Soviet situation map of the battle of Szczecin between 20-25 April 1945.

FIGURE 9

Aerial photo of the bombing of the Szczecin area.

FIGURE 10 & 11

Bombing of the city of Szczecin.

For the southern section of the fairway, the campaign focussed on the expectation of the following UXOs:

- bombs up to 1,000 kg;
- UK and German (aluminium) ground mines; and
- artillery up to 203 mm.

Specific challenges

The historical research concerned the main "foundation" for the investigation and removal campaign. Second "pilar" concerned the requirements and parameters under the main contract. Especially in the Szczecin region where various shipyards do exist and extensive port activities take place, clustered areas of ferrous objects could be expected on the fairway bottom. All in all this resulted in an extensive campaign within an active fairway.

UXO approach

As part of the preparations of the investigation and removal works the following approach was taken:

1. Research of historic events to identify expected UXO's in areas.

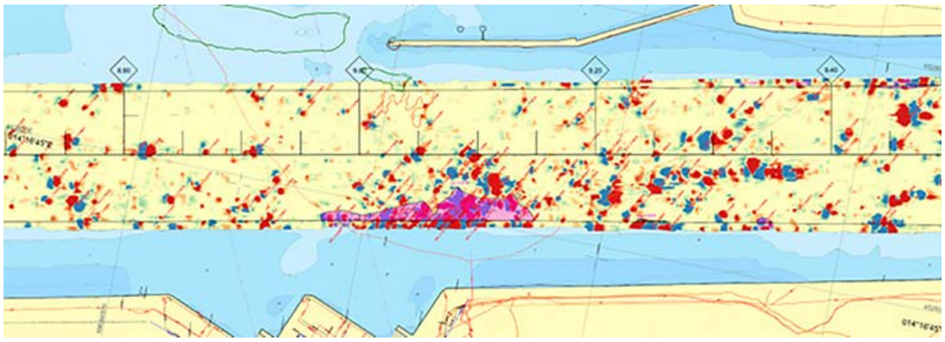


FIGURE 12

Combined overview magnetometer results.

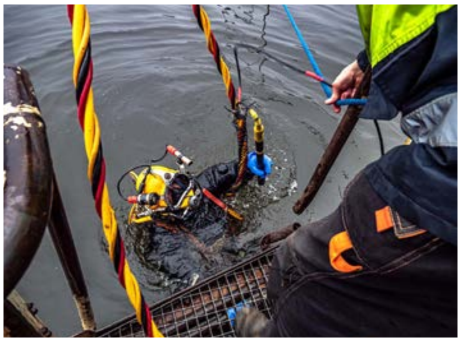


FIGURE 13

UXO trained diver using handheld magnetometer.

2. Project specific UXO Risk Assessment (URA)
   - Evaluate risk to crew and equipment per activity and assess the impact.
   - Trailer suction hopper dredger/cutter suction dredger/backhoe dredger.
   - Cable removal and installation works/ sheet and jetty pile installation/rock installation.
3. Evaluate site conditions (water depth, soils, morphology) to determine penetration depths.
4. Define threshold values.
5. Produce Master Target List (MTL).

The Master Target List(s) concerned the main output of the investigation campaign and the starting point for the clearance works.

Investigation and preparation

To obtain the required Master Target List (MTL), as part of the UXO investigation works, a large-scale survey campaign took place. This campaign covered the full footprint of the existing fairway between Świnoujście and Szczecin, and consisted of the performance of various survey methods:

- a bathymetric (multi-beam) survey to determine the existing seabed depths;
- a magnetometer (MAG) survey to detect the ferrous objects of interest; and
- a side scan sonar (SSS) survey and (for specific sections of the fairway) a time-frequency electromagnetic (TFEM) survey to detect large non-ferrous objects of interest (e.g. aluminium mines).

With the survey data obtained, a Master Target List (MTL) was created for the various dredging sections of the fairway.

Throughout the preparations of the clearance campaign, it was decided to divide the project area into separate sub-areas and to appoint the subcontractors performing the removal works accordingly. This allowed for more efficient follow up and increase productivity accordingly. These subcontractors were allowed to work in the various sections at the same time – a chosen strategy which worked out well.

Removal works

Two different removal methods were used to execute the clearance works: removal by UXO trained divers with a handheld magnetometer and investigation and removal by means of a remote operating device (ROD).

Mainly in the southern part of the working area near the city of Szczecin, areas with ferrous objects were tackled in a two-phase approach. After approaching and removal of the initial number of targets on the Master Target List, a second survey by means of magnetometer was performed and the remainder of ferrous objects removed.

Overall, an astonishing 1,800 unexploded ordnances and related items were removed as part of the removal campaign.

Mitigation measures during dredging

Upon completion of the clearance works, a third-party UXO clearance certificate for the various fairway sections was obtained. To cater for any potential threat, which would have been undiscovered by the extensive clearance campaign, some further additional mitigation measurements were implemented throughout the deepening and widening of the fairway.

Among others, this included:

- UXO awareness training for both staff and crew directly involved in the dredging campaign;
- a bomb grid in the drag head of each trailing suction hopper dredger employed;
- 24/7 third-party EOD experience and supervision on board of the main dredging equipment; and
- UXO storage containers on board of the main dredging equipment to store any UXO's encountered.

FIGURE 14

Investigation and removal by remote operating device (ROD).

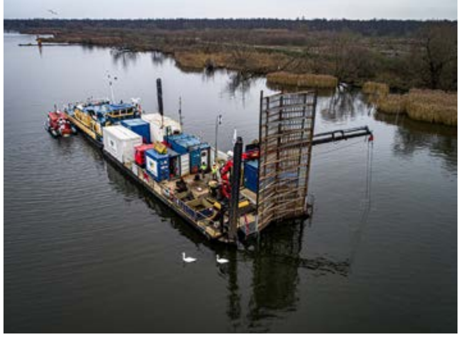


FIGURE 15

Executing the clearance works in the fairway.

One of the third-party UXO experts described the campaign as "likely the most comprehensive and largest UXO clearance project ever realised in inland waterways". It can be concluded that the dredging and reclamation activities and other related work scopes have been executed

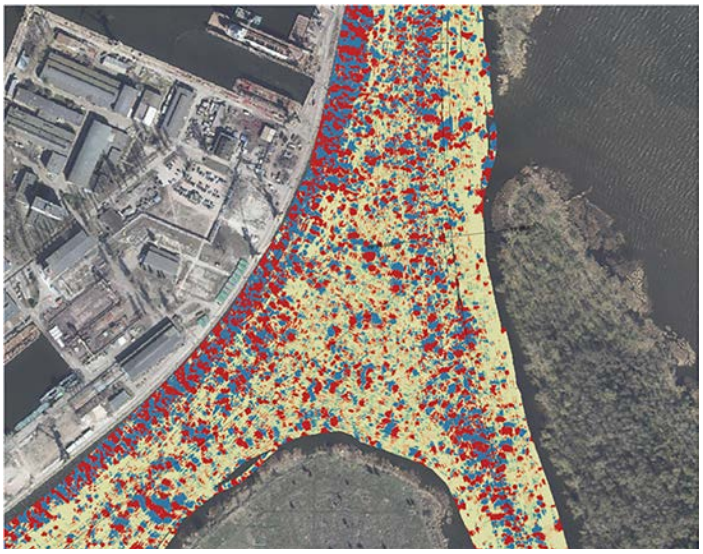


FIGURE 16

Polluted areas showing the extensive amount of objects in the city of Szczecin.

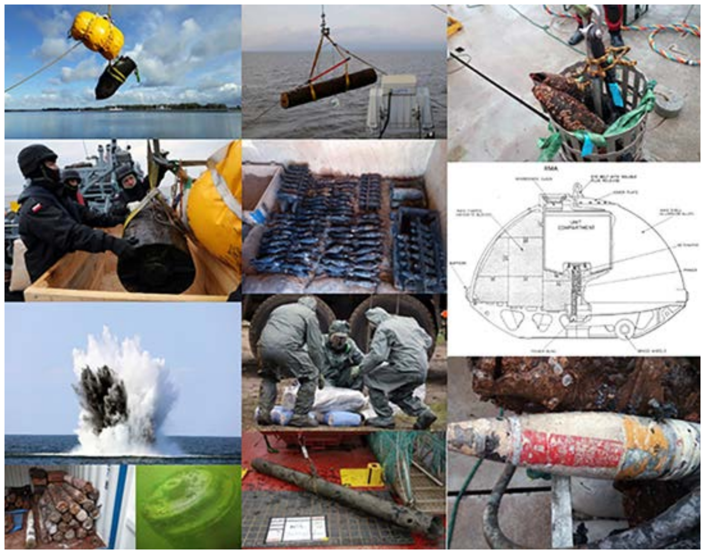


FIGURE 17

Impression of UXO findings in fairway removal campaign.

in an environment without any potential UXO threat to the workforce and equipment employed.

Dredging and reclamation

The dredging works within the project area were spread over a channel length of approximately 62 kilometres and took place over a period of two years (Q2 2020 to Q1 2022).

TSHD Scheldt River, Meuse River and Vox Amalia, as well as CSD Amazone and Spreader barge HAM 1208 were, among other auxiliaries, deployed to dredge and reclaim approximately 24.5 million m3. All of the dredged material was reclaimed within two artificial islands in the middle of the Szczecin Lagoon and most of the material was pumped hydraulically from the fairway to the islands by use of pipelines.

At the island of Ostrow Gabrowski in the Port of Szczecin, a new turning circle to accommodate the larger vessels was also envisioned. This involved the removal and capital dredging of the existing headland by grab, bucket and backhoe dredger. All material was transported with barges and dumped inside of one the islands.

FIGURE 18

Detonation "Tallboy" in fairway on 13 October 2020.

Challenges

Although the dredging and reclamation scope within this project might have seemed straightforward, there were several challenging elements to overcome:

- **COVID-19 pandemic:** The COVID-19 pandemic that began in March 2020 could not have come at a worse time since preparations were ongoing to mobilise the CSD Amazone and kick-off the long-awaited dredging campaign. Thanks to the relentless efforts within the joint venture and good cooperation with the client, the works began in May 2020. During the entire dredging campaign, additional measures were implemented in the site offices and on the islands to limit the exposure and spread of COVID-19, including daily PCR testing, no visitors on board the vessels, crew travelling in "bubbles", etc. As a result, the impact of the pandemic on operations was limited.

- **Active fairway:** Although it was known during the preparation phase that the fairway would remain active during the entire dredging campaign, the coordination efforts were elevated due to a more extensive than expected UXO removal campaign, which continued during the dredging works.

- **Long pumping distances:** Again, a challenge which was foreseen during the preparation phase and required dedicated TSHD's that were both versatile enough for the narrower and shallower parts of the channel as well as outfitted for the pumping distances up to 6.5 kilometres (8 kilometres for the CSD). Thanks to the modern fleet of both Van Oord and DEME, the right equipment was available within the joint venture and no booster stations had to be deployed during any phase of the project. A total of 10 kilometres of sinker line and floating pipelines were mobilised to accommodate the long pumping distances.
- **Environmental requirements and restrictions:** The environmental sustainability and cooperation with all project stakeholders played an important role during execution. Several dredging areas were restricted during fish spawning period and the water quality within the full project area was monitored during the whole execution phase. On the islands and along the fairway trees and bushes were planted and various habitats were created to compensate for the impact of the deepening works on the environment. Especially for the islands this required several additional design alterations to include all environmental needs.
- **Ice period:** Over the winter of 2020-2021, the whole fairway and lagoon froze during the peak of dredging and reclamation works. Two TSHD's (Scheldt River and Vox Amalia) were working at that moment and reclamation was ongoing on both islands. So operations had to be paused, vessels were demobilised during that period and works could only be resumed when the channel was approachable again. Several rectification works were required along both islands due to the ice impact.

Environmental aspects

The Szczecin lagoon is a Natura 2000 area and also large parts of the riverbanks are protected nature reserves. Of course, and as a minimum, all works were done in line with the environmental permit obtained by the client.

The entire dredge volume was used for the establishment of two artificial islands, which represents a very sustainable and environmentally advantageous concept. This solution was developed by the initiators of the fairway project from the start.

Additionally, in striving to go a step beyond the formal requirements, the joint venture looked for possibilities to do better, promoting "green initiatives" focusing on using sustainable resources to limit the impact of the works as much as possible. Some of the implemented measures included:

- **Greenery design:** on the island envisioned as a bird habitat, a greenery design was made as nature compensation (planting of tree, shrubs, etc.), including the creation of an internal lake. Even during the works, the island already proved very attractive as a bird habitat, to the extent that part of the works had to be replanned/scheduled to fence off areas where birds had started to nest.
- **Logistics hub:** the small port and marina of Trzebież was used as a site office and logistics hub. Located 30 kilometres

FIGURE 19

New habit for flora and fauna on the northern island.

FIGURE 20

New donut-shaped soil depot on the southern island.

	Location	Indication length to be removed (m)	Indication length to be installed (m)
01	KP9 - marine	325 ml	1,000 ml
02	KP9 - land	-	1,100 ml
03	KP40	1,100 ml	1,100 ml

TABLE 1

Vessel Traffic Services (VTS) cable scope (KP9 and KP40).

	Description	KP	Overall length of sheet piles (top view)
01	Bon Wharf	60,800 - 61,200	95 ml
02	Zeglarskie Wharf	60,100 - 60,300	207 ml
03	Radolin	62,700 - 63,500	530 ml
		TOTAL	**832 ml**

TABLE 2

Overview of overall length of sheet pile works.

closer than Szczecin to both islands, this reduced the transport distances for all supplies and resources from and to the islands. Solar panels were installed in the marina of Trzebież to encourage the use of renewable energy.

- **Use of LNG as fuel:** TSHD Scheldt River is an innovative dual fuel trailing suction hopper dredger that executed a large part of the dredging works. In cooperation with the Maritime Office in Szczecin, the first LNG bunkering of a dredging vessel in Polish waters was completed in the Port of Szczecin in 2020.
- **Bunkering within the lagoon:** to avoid the mob/demob of CSD Amazone from the dredging area in the centre of the Szczecin Lagoon to the nearest port, a procedure was developed that allowed bunkering next to the fairway.
- **Fish spawning and water quality monitoring:** an ichthyologist was hired by the project to monitor the fish spawning in the lagoon and river. Continuous sampling was done to monitor the siltation.
- **Spreader HAM1208:** during the underwater bund construction of both islands, a dedicated spreader pontoon was used by both CSDs and TSHDs to limit any siltation plume within the lagoon.
- **Reclamation equipment:** hybrid Caterpillar D6 bulldozers were deployed to reduce the fuel consumption of the dry earth moving equipment.
- **Water usage:** instead of ferrying potable water from the shore to both islands for the reclamation crew, pumps and filters were installed so the water from the lagoon could be used for sanitary purposes.

Other construction works

In addition to the above mentioned works, there were many other auxiliary scopes that were executed under the contract. Although proportionally smaller in size, they were at times very complicated and thus created their own challenges which, with the help of local subcontractors who shared their local know how and expertise, had to be addressed.

Cables installation and removal

As part of the full project scope of works, at various locations along the fairway, inactive cables crossing the fairway near Szczecin harbour had to be removed.

Furthermore, due to the deepening and widening of the fairway, the existing Vessel Traffic Services (VTS) cable had to be partly removed and reinstalled, all while maintaining this important communication method for active shipping traffic. One of the installation techniques used alongside Debina Island was HDD – Horizontal Directional Drilling. Table 1 shows the exemplary lengths of VTS cables used for the works.

Sheet piling

As mentioned under the design, in order to protect existing structures from the deepening works, sheet pile walls had to be installed along the fairway near the city of Szczecin at the berths of Bon, Zeglarskie and Radolin.

At Bon and Zeglarskie, sheet piles were driven into the bottom of the fairway and backfilling works behind the new sheet pile wall were executed to provide protection. At Radolin (cofferdam construction) sheet-piles were driven into the bottom of the fairway.

Thereafter installation of the anchors, waling beam, capping plate and tie-rods in the cofferdam area was completed, followed by the installation of the shore lights and backfilling works of the cofferdam area. Table 2 provides general details on locations and quantities of sheet piling.

Navigational aids

Various navigational aid related works were part of the full project scope of works. This included:

- removal of an existing beacon and supply and installation of a new beacon at the Ostrow Gabrowski peninsula;
- removal of existing dolphins and installation of new dolphins as a result of the widening of the fairway at some locations;
- supply and installation of shore lights along the fairway at Radolin and Wielka Kepa islands;
- supply and installation of navigational aids at the jetty structures on the artificial islands;
- supply of buoys for the widening of the fairway at the Szczecin lagoon and around the artificial islands; and
- renovation of the power supply at Gate IV of the fairway.

Conclusions

The dredging and reclamation scope of the project was one of the biggest capital dredging projects within Europe over the past 20 years.

FIGURE 21

Aerial view of the work harbour in Trzebież during the ice period in 2021.

The combination of the largest UXO investigation and removal campaign, the creation of two islands (approx. 3 kilometres and approx. 8 kilometres from the nearest shore), the onset of COVID-19 and a harsh winter created exceptional challenges that the project team had to overcome.

The joint venture succeeded in building the two islands within Szczecin lagoon and deepen the fairway between Świnoujście and Szczecin to -12,5 metres within three years. This was accomplished by great teamwork between DEME and Van Oord and an excellent cooperation with the client – the Maritime Office in Szczecin.

The modernisation of the fairway from Świnoujście to Szczecin takes the performance of this waterway to the next level and ensures environmentally friendly, effective transport of goods to the hinterland of Western Pomerania and further south for years to come.

With the reuse of the dredged soil as building material for the two artificial islands in the Szczecin lagoon, the gentle and careful integration of the existing bank structures into the new infrastructure and the cleaning of the canal from polluting residues from the last century, the principles of sustainability were followed in an exemplary manner and excellent ecological accents set.

The idea of the founders of this groundbreaking project therefore became reality in two senses, being both a win for the economy and a win for nature.

Summary

The deepening of the Świnoujście – Szczecin Fairway is one of the most important dredging projects in Poland's history. Providing access from the Baltic Sea, the fairway runs between the city of Świnoujście and the Port of Szczecin. With more approximately 24 million m³ of material dredged, the channel was deepened by 2 metres to -12.5 metres, enabling the port of Szczecin to handle the next generation of vessels.Despite exceptional challenges, including carrying out most of the work during the pandemic and the presence of large amounts of unexploded ordnance, as well as thick ice in winter, the ambitious project was completed on time, highlighting the tremendous efforts of the JV team, and was handed over to the Maritime Office in Szczecin in the spring of 2022.

Benny Anthonissen

Benny joined DEME in 2008 and for the first part of his career worked all over the world on board Trailing Suction Hopper Dredgers as Chief Mate. In 2015, he changed career path and became a superintendent on the Tuas Terminal Phase 1 project in Singapore. From 2018-2022 he was Head of Operations for all dredging and reclamation works on the Świnoujście – Szczecin Fairway project for DIVO. Currently Benny is working as Construction Manager for the Darsena Europa port expansion project in Livorno, Italy.

Boris Vandekerckhove

Boris studied industrial engineering in Belgium and joined DEME group in 2012 as a cost estimation engineer within the tender department. Within this role he also spent some time abroad to assist ongoing projects. At the beginning of 2018, Boris became the Tender Manager for DIVO, for the Świnoujście – Szczecin Fairway project. He joined the project after the award and became the head of the Project Controls Department until the end of the project. Currently Boris works as a Programme Manager on internal DEME projects.

Gijs van Zalk

Gijs studied civil engineering in the Netherlands and the United Kingdom, and joined Van Oord in 2002 as a Project Engineer. During his career, he has worked in various operational roles on dredging and marine projects around the globe. Since 2011, Gijs has worked as a project manager in India, Australia, Indonesia, Maldives, the Netherlands, Poland, Kingdom of Saudi Arabia and the United Arab Emirates. On behalf of the DIVO joint venture he was responsible for the execution of the UXO investigation and removal campaign, the construction works and the greenery scope. Currently Gijs is working as Project Manager in Dubai.

Hugo Lavies

Hugo studied hydraulic engineering at Delft University of Technology, in the Netherlands. In 2015, he joined Van Oord and after a year as a technical trainee he started working for the coastal engineering department. He supported on multiple projects in both tender, preparation and execution stage. In early 2020, Hugo joined the DIVO project team as Design Manager, continuing the work of his predecessors and worked for and at the project till its finalisation in 2022. Currently Hugo is working on the design for the protection and rehabilitation projects in Constanta, Romania.

References

DEME (2021)
Unexploded Ordnances (UXO) management manual.

Van Oord (2021)
Safe work practice Unexploded Ordnances (UXO). QHSE department, Van Oord. Reference QHSE-HSE-PU-SWP-044 / #3190456, 6 June 2021.

UPCOMING COURSES AND CONFERENCES

CEDA's (revamped) Dredging Days 2024
27-29 May 2024
WTC Rotterdam, Rotterdam, the Netherlands
https://www.cedaconferences.org/dredgingdays2024

CEDA's 3-day stand-alone conference (no longer combined with Europort), provides a forum for leading researchers and industry experts to share ideas, discuss challenges and consider potential solutions. The conference is well-attended by professionals representing the entire cross-section of the dredging field, from across the CEDA region and beyond. The dredging community has proven its ability to adapt to a changing world, by leading, innovating and being open to collaboration. To reflect this spirit even more, CEDA has revamped its Dredging Days programme for the 2024 edition, where it will engage with the theme "Dredging in a changing world, leading science and business in the dredging industry".

One main feature of the revamp is the addition of a central Clubhouse, which focuses on networking in an intimate setting. The Clubhouse will replace the formal exhibition set up with stands and create an informal lounge area where attendees can relax and engage in conversations with their peers at any time during the conference.

Dredging and Reclamation Seminar
1-5 July 2024
IHE Delft Institute for Water Education
Delft, The Netherlands

About the seminar
Since 1993, the IADC has regularly held a week-long seminar developed especially for professionals in dredging-related industries. These intensive courses have been successfully presented in the Netherlands, Singapore, Dubai, Argentina, Abu Dhabi, Bahrain and Brazil. With these seminars, IADC reflects its commitment to education, encouraging young people to enter the field of dredging and improving knowledge about dredging throughout the world.

For whom
The seminar has been developed for both technical and non-technical professionals in dredging-related industries. From students and newcomers in the field of dredging to higher-lever consultants, advisors at port and harbour authorities, offshore companies and other organisations that carry out dredging projects. Attendees will gain a wealth of knowledge and a better understanding of the fascinating and vital dredging industry.

In the classroom
There is no other dredging seminar that includes a workshop covering a complete tendering process from start to finish. The in-depth lectures are presented by experienced dredging professionals from IADC member companies. Their practical knowledge and professional expertise are invaluable for in the classroom-based lessons. Among the subjects covered are: the development of new ports and maintenance of existing ports; project development: from preparation to realisation; descriptions of types of dredging equipment; costing of projects; types of dredging projects; and environmental aspects of dredging.

Site visit: seeing is believing!
Practical experience is priceless and it sets aside this seminar from all others. There will be a site visit to a dredging yard of an IADC member to allow participants to view and experience dredging equipment first-hand to gain better insights into the multi-faceted field of dredging operations.

Networking
A mid-week dinner where participants, lecturers and other dredging employees can interact, network, and discuss the real hands-on world of dredging provides another dimension to this stimulating week.

Certificate of achievement
Each participant will receive a set of comprehensive proceedings and at the end of the week, a certificate of achievement in recognition of the completion of the coursework. Full attendance is required to attain the certificate. For more information and how to register visit https://bit.ly/SemDelft2024.

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