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Pro-Ecological Water-Jetting Technologies (and High-Pressure Equipment) Application in Shipyard Repair Industry

Przemysław Borkowski
Koszalin University of Technology

1. Introduction

Methods of stripping the damaged coatings and corrosion from ship's hulls using the high-pressure abrasive-water jet and ultrahigh-pressure water jet are intensively developed nowadays. Such development is oriented mostly on automation of the cleaning process [12, 16], especially using the adsorptive running carriage-type robots [17, 19], emission-free surface preparation [15] or using the pulsed water jets [18]. Application of new surface preparation methods with water jetting requires the previous principles, conditions and standards of cleaning [10, 13] to change, which were supported by versatile trade-off studies [9] on previous and new methods of ship's hulls surface treatment. Finally, the trend of decoating process by ultra high-pressure pure waterjets [14] has prevailed opening new prospects for development [11, 16].

However, application of new methods of stripping old coatings in domestic shipyards is limited regarding high costs of adequate technological equipment. The situation in small repair shipyards still looks much worse and it is difficult to introduce a cleaning process based on high-pressure abrasive-water jetting technology [1-6] there. Therefore, using the adequate sprinklers [7] fitted with proper concentric nozzles [8] may be of great importance in such circumstances. Considering world tendencies, there are presented here some results of own research, which make it easy to select peripheral technological equipment and conditions for such decoating operations.

2. High-Pressure Manually Operated Equipment

Efficient ship's sides treatment using the high-pressure abrasive-water jet in the first instance requires selection of proper technological equipment, e.g. a sprinkler of special design suitable for such decoating. Actually, there are a lot of such technological equipment available on the market. Some examples of that could be manually operated working heads (Fig. 1), surface cleaners (Fig. 2) or guns (Fig. 3 and Fig. 4) equipped with different non- (Fig. 5) and rotating (Fig. 6, and Fig. 7) constructions of working heads. On the other hand, such equipment usage needs special safety valves (Fig. 8) that stops dynamic hydraulic stroke occurring e.g. during double stand high-pressure operation. Accurate high-pressure equipment selection will be possible only when operating conditions are established properly.

Fig. 1. Example of manual cleaning units using high-pressure water jet Aquablast® Hand Held type FRWV 3000
Rys. 1. Przykład ręcznego urządzenia wykorzystującego wysokociśnieniowy strumień cieczy Aquablast® Hand Held typ FRWV 3000

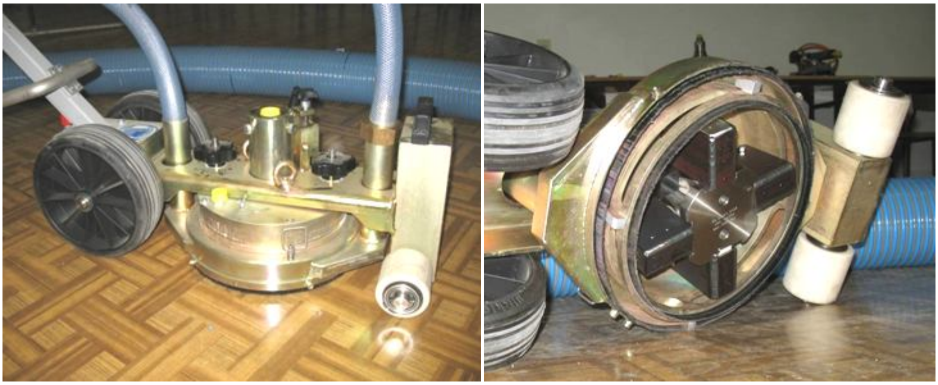

Fig. 2. Example of hand operated cleaning trolley using high-pressure water jet Aquablast® – Plus type FRV 3000

Rys. 2. Przykład ręcznego wózka czyszczącego wykorzystującego wysokociśnieniowy strumień cieczy Aquablast® – Plus typ FRV 3000

Fig. 3. Examples of high-pressure guns of lance type made by Woma and NDMNC manufacturers

Rys. 3. Przykłady wysokociśnieniowych pistoletów typu lanca produkowanych przez Woma i NDMNC

Fig. 4. Examples of high-pressure rotating guns type SP 3000 PR2 (above) and SP 3000E (below)
Rys. 4. Przykłady wysokociśnieniowych pistoletów rotacyjnych typu SP 3000 PR2 (wyżej) i SP 3000E (niżej)

Fig. 5. Examples of high-pressure stationary working heads
Rys. 5. Przykłady wysokociśnieniowych nieruchomych głowic roboczych

a) b)

Fig. 6. Examples of high-pressure rotary working heads type RTH, RTK and RTV (a), RD Flex 3000 (b)

Rys. 6. Przykłady wysokociśnieniowych rotacyjnych głowic roboczych typu RTH, RTK i RTV (a), RD Flex 3000 (b)

Fig. 7. Examples of high-pressure slow motion rotary working heads equipped with its regulation systems type RD 1500 (left), RDM 250 (center) and Aquamat XL 1500-2 (right)

Rys. 7. Przykłady wysokociśnieniowych wolnoobrotowych głowic roboczych z systemem regulacji typu RD 1500 (po lewej), RDM 250 (w środku) i Aquamat XL 1500-2 (po prawej)

Fig. 8. Example of high-pressure multi stand safety valve type ECMTV 3000
Rys. 8. Przykład wielostanowiskowego, wysokociśnieniowego zaworu bezpieczeństwa typu ECMTV 3000

3. Abrasive-Water Jet Sprinkler Selection

Selection of peripheral equipment for above mentioned operations depends mainly on possibilities of decoating process mechanization and a stage of automatic control [12]. Manually operated equipment such as lances and sprinklers [1, 6] are used for that purpose. The most important structural components determining the effectiveness of the sprinkler [5, 7] operation is a multioutlet concentric nozzle and a tube (that are set in a countershaft mounted on a typical high-pressure spray gun) that are selected in the first instance.

Detailed information concerning sprinkler construction and its optimization were presented in another paper [3]. Therefore hereby information is limited to explain only main optimization criterion and results of sprinkler optimization.

First, elimination tests were carried out in order to establish proper conditions for implementation of optimization examinations that enabled to confront usability of different concentric nozzles and tubes. About 20 physical values were analyzed and technological criterions describing the abrasive-water jet, which enabled among others to select proper criterions for an objective and comprehensive estimation of the jet useful properties created inside the optimized concentric nozzle and the tube. Objective main criterion is cost per piece, which is:

$$C_p = \frac{\rho_a \rho_m}{3{,}6} \cdot \frac{C_w + C_e + C_m}{Q_a \cdot E_r} \quad , \qquad [\mathrm{PLN/cm^3}] \qquad (1)$$

(its connection with abrasive consumption $\{Q_a\}$ [g/s] and abrasive-water jet erosiveness $\{E_r\}$ [g/dm^3] is illustrated by above formula, in which besides abrasive density $\{\rho_a\}$ and material density $\{\rho_m\}$, occurs a unit costs of: work $\{C_w\}$, equipment working motion $\{C_e\}$ and material $\{C_m\}$, that are supplied with a converter from hours to seconds).

Experimental results enabled to optimize this nozzle in aspect of many factors describing useful properties of high-pressure abrasive-water jet. Owing to that it was possible to specify optimal concentric nozzle parameters and finally to produce it. Useful jet properties of that nozzle made it possible to describe its characteristic features and technological usefulness in the cleaning process.

On the basis of these results it was possible to assume that optimized nozzle construction is characterized by the following features:

- P type concentric nozzle, that means a nozzle with radius R_w = 9.7 mm;
- nozzle central hole diameter D_0 = 15.45 mm;
- nozzle water hole number n_w = 6;
- water hole diameter d_w =1.3 mm;
- water hole axis angle ε = 5°30′;
- water hole length l_w = 8.35 mm.

Similar planned multi-criterial investigations were connected to optimization of the sprinkler tube construction taking into account its diameter and length. Examinations gave many results and the most spectacular are those illustrating examined relations: sprinkler tube diameter influence on costs per piece of abrasive-water cleaning operation and it follows that the minimum cleaning costs are characteristic for D_k = 22 mm diameter tubes. Example results of the sprinkler tube length influence on the operation costs per piece are shown in Fig. 9. It shows that tube length increase is profitable in the aspect of abrasive-water jet erosiveness, which reaches the best effects for tube length range 160÷200mm.

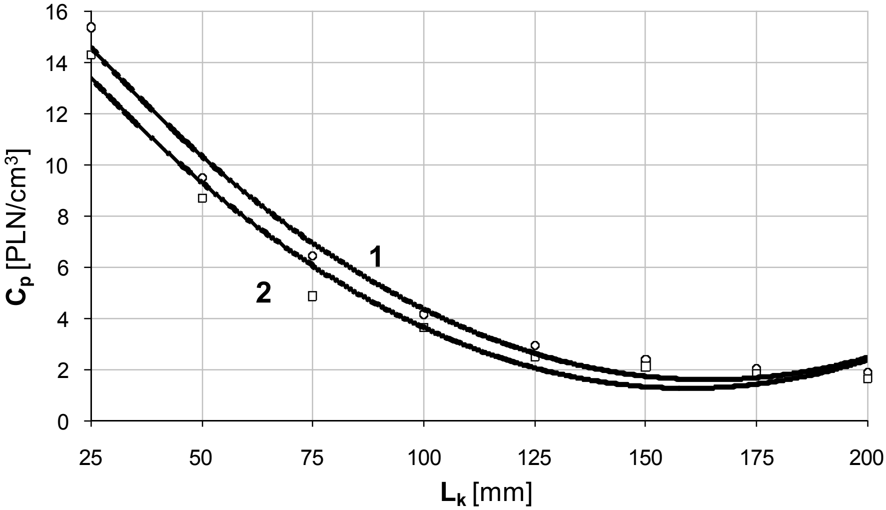

Fig. 9. Sprinkler tube length (L_k) influence on the cost per piece (C_p) for two type concentric nozzles: 1 – 4x1.2mm; 2 – 6x1.2mm. (p_n= 20MPa, SiO_2 #36; L=500mm, D_k= 22mm)

Rys. 9. Wpływ długości rurki rozpryskiwacza (L_k) na jednostkowy koszt (C_p) dla dwóch typów dysz koncentrycznych: 1 – 4x1,2mm; 2 – 6x1,2mm. (p_n= 20MPa, SiO_2 #36; L=500mm, D_k= 22mm)

This way optimized sprinkler construction ensures efficient surface treatment. Selection of concentric nozzle design features could be carried out on the basis of results (Fig. 10) obtained during the investigations on maximization of metal plate cleaning efficiency. Therefore the best result was obtained for six-outlet nozzle with water jets d_w=1.3 mm in diameter, where radius of their spacing was equal to R=9.8 mm, while the central suction nozzle was D_o=15,6 mm in diameter.

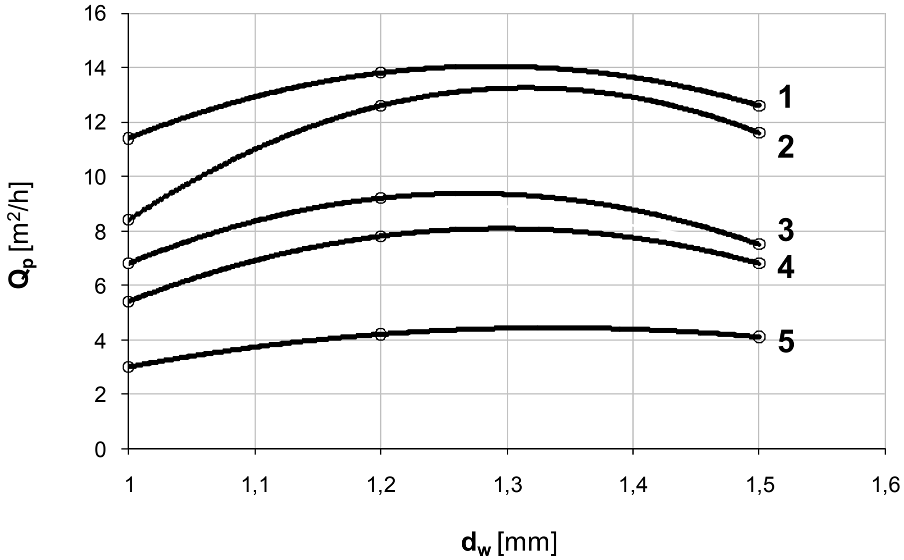

Fig. 10. Influence of water-nozzle dimension on cleaning efficiency using the high-pressure abrasive-water jet created in different six-outlet concentric nozzles: 1 – for R_w=9.8mm and D_o=15.6mm; 2 – for R_w=11mm and D_o=18mm; 3 – for R_w=6.4mm and D_o=12.75mm; 4 – for R_w=11mm and D_o=15.6mm; 5 – for R_w=11mm and D_o=12.75mm. (L_k=200mm, p_n=30MPa, SiO_2 #36)

Rys. 10. Wpływ rozmiaru dyszy wodnej na skuteczność oczyszczania przy zastosowaniu wysokociśnieniowego ścierania hydrostrumieniowego uzyskane dla różnych sześcio-wylotowych dysz koncentrycznych: 1 – dla R_w=9,8mm i D_o=15,6mm; 2 – dla R_w=11mm i D_o=18mm; 3 – dla R_w=6,4mm i D_o=12,75mm; 4 – dla R_w=11mm i D_o=15,6mm; 5 – dla R_w=11mm i D_o=12,75mm. (L_k=200mm, p_n=30MPa, SiO_2 #36)

4. Technological Applications For Manual Equipment

Water jets in the above testing were additionally admixed with traditional abrasive, mostly natural sand quartz characterized with granularity range of 0.2÷1.2 mm. Some initial investigations revealed relatively efficient cleaning of corroded steel plates of ship's hulls.

As it turns out in practical conditions, much more profitable is a application rotating ultrahigh-pressure water jet (about 300 MPa). Such water jets are created in the head of a high-pressure handgun (Fig. 11).

Fig. 11. Application of high-pressure gun equipped with super fast rotary RD 3000 type working head made by Hammelmann that includes magneto-dynamic brake
Rys. 11. Zastosowanie pistoletu wysokociśnieniowego z superszybką głowicą rotacyjną typu RD 3000 produkcji Hammelmann z hamulcem magneto-dynamicznym

These are highly penetrating jets practically forcing in each cleaned recess of object, removing all particles about the smaller endurance. However, considering the relatively restrained output (usually about 10 m^2/h) this kind sprinkler accessory is principally dedicated for hard to reach surface about the large curvature etc.

Moreover, for the assurance of safe work conditions during the processing, with simultaneous use of several hand controlled handguns and other high-pressure equipment, it is necessary to apply so called multi-stand safety valve (Fig. 8). This equipment stops unwanted dynamic strokes occurring in the moment when one operator switches off the handgun. Of course, to supply this technological equipment with high-pressure water, it is a necessity to use appropriate high-pressure pumps (Fig. 12) and flexible hoses ensuring the highest standards of safety.

Fig. 12. General view of mobile high-pressure hydromonitor including high-pressure pump type HDP 164 (p_{max}=300 MPa, Q_{max}=30 dm^3/min)
Rys. 12. Widok mobilnego wysokociśnieniowego hydromonitora z pompą wysokiego ciśnienia typu HDP 164 (p_{max}=300 MPa, Q_{max}=30 dm^3/min)

More effective then mentioned hand guns, it is application of appropriate manual working heads (Fig. 13). They usually work with the water pressure of about 300 MPa and expense of water of 20 dm^3/min. That assures rotational velocity of rotor about 2500 rpm and process efficiency level of 25 m^2/h for the cleaning width of about 150 mm. Still higher effects are characteristic for high-pressure trolleys exemplary shown in Fig. 14a, that works with near hydro-technical parameters but twice larger expense of water and for the half of a larger diameter of rotor cleaning flat surfaces with the output reaching up to 40 m^2/h. However to achieve water and output suction from this kind equipment it is necessary to apply addition vacuum equipment (Fig. 14b) working with expense at least 200 m^3/h giving the suction level of 20 kPa.

Fig. 13. Application of high-pressure manual working head Hand Held AQUABLAST type FRWV 3000
Rys. 13. Zastosowanie ręcznej głowicy wysokociśnieniowej Hand Held AQUABLAST typu FRWV 3000

a) b)

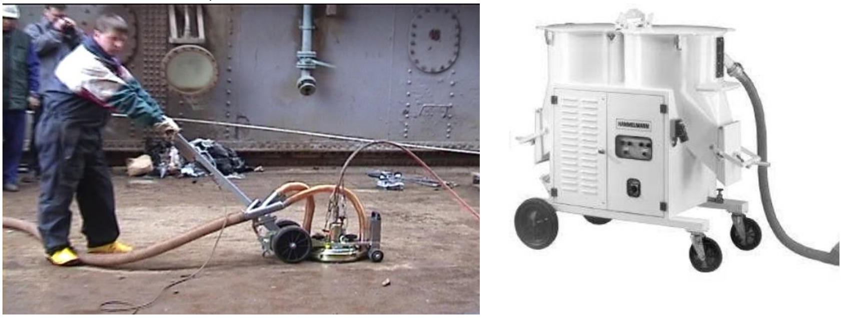

Fig. 14. General view and application of high-pressure trolley AQUABLAST type FRV 3000 (a) and Vacuum Unit type AQUABLAST (b)
Rys. 14. Widok i zastosowanie wysokociśnieniowego wózka AQUABLAST typu FRV 3000 (a) i Vacuum Unit typu AQUABLAST (b)

5. Technological Applications Of Mechanized Equipment

Application of ultrahigh-pressure water jet is particularly useful in the processing and the cleaning of extensive surfaces about any angle eg: ship's hulls, containers, chimney freezers and so one. A special high-pressure water machine tools are applied into that application, for example: the SpiderJet 3000 (Fig. 15). This is remotely controlled self-propelled equipment (Fig. 16) that includes hermetically protected working zone which adheres to the surface thanks to the vacuum effect. This type cross rotor (Fig. 17) is about 370 mm in diameter and is equipped with specific combination of high-pressure water nozzles.

Fig. 15. SpiderJet during ship's hull cleaning in "GRYFIA" shipyard
Rys. 15. SpiderJet w czasie czyszczenia kadłuba statku w stoczni „GRYFIA"

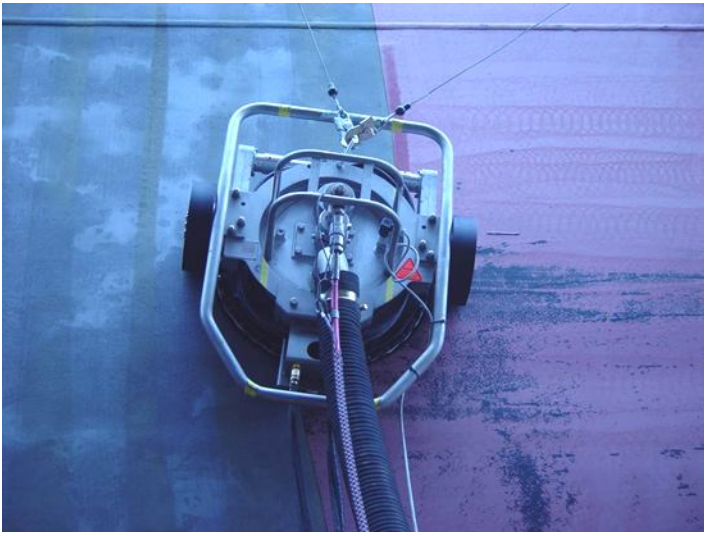

Fig. 16. Self-mobile full recovery waterjet stripping system AQUABLAST type SpiderJet 3000
Rys. 16. Samojezdny system abrazyjny AQUABLAST SpiderJet 3000 z pełnym odbiorem

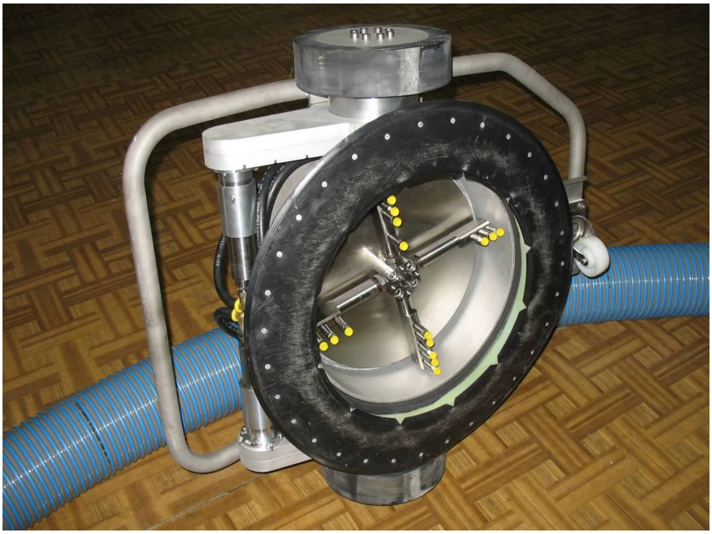

Fig. 17. View of SpiderJet 3000 inside showing rotor with nozzles and suction gasket (on the first stage)
Rys. 17. Widok wnętrza SpiderJet'a 3000 z wirnikiem z dyszami i uszczelnieniem odsysającym (na pierwszym planie)

Nozzles of SpiderJet are supplied by a high-efficiency hydromonitor (Fig. 12 or Fig. 18) through the high-pressure hoses. Typical hydraulic parameters of such work are equal to p_{max}=300 MPa, Q_{max}=50 dm^3/min assuring removal of cover and primal paint to „clean sheet metal" with efficiency reaching the level up to 80 m^2/h.

Fig. 18. General view of high efficient (Q_{max}=155 dm^3/min) diesel hydromonitor equipped with high-pressure (p_{max}=150 MPa) pump type HDP 483

Rys. 18. Widok wysokosprawnego (Q_{max}=155 dm^3/min) hydromonitora wyposażonego w pompę wysokiego ciśnienia (p_{max}=150 MPa) typu HDP 483

For water and output sucked off the working zone, a SpiderJet is connected to high-efficiency vacuum aggregate using suction hoses. Such aggregate generates the vacuum assuring appropriate conditions of SpiderJet suction, simultaneously giving freedom of working movements, but moreover assuring efficient sucking off water and of erosion products. Such condition assures Vacuum Extractor type DV 3001 D KI ESS (Fig. 19), which generates vacuum of 50 kPa with the expense over 2600 m^3/h.

Fig. 19. General view of Vacuum Extractor aggregate type DV 3001 D KIESS including cyclone pollutants separator
Rys. 19. Widok agregatu ekstraktora próżniowego typu DV 3001 D KIESS wyposażonego w cyklonowe separatory zanieczyszczeń

6. Conclusion

Technologies introduced up to know in Polish repair shipyards are not only environmentally hazard but what is more important contribute to creation of so called work diseases. It concerns mostly corrosion removal using low efficient method of sand blasting what causes dustiness in the range of few hundred meters. In opposition to that, water jetting technologies basing on erosive properties of high-pressure water jet are definitely free of above effects.

Presented paper shows contemporary technologies introduced in leading shipyards all around the globe as well as the newest constructions of high-pressure equipment that is in the possession of the Unconventional HydroJetting Technology Center. One of the main advantage of such jetting technology is its high efficiency comparing to traditional techniques and its environmental cleanness.

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Zastosowanie proekologicznych technologii hydrostrumieniowych (oraz sprzętu wysokociśnieniowego) w przemyśle stoczniowo-remontowym

Streszczenie

Metody usuwania zniszczonych pokryć i korozji z kadłubów statków przy zastosowaniu wysokociśnieniowych wodnych technik ściernych oraz ultra wysokociśnieniowych technik hydrostrumieniowych obecnie intensywnie rozwijane. Taki rozwój jest ukierunkowany głównie na automatyzację procesu czyszczenia [12, 16], w szczególności poprzez stosowanie robotów typu wózek [17, 19], bezodpadowe przygotowanie powierzchni [15], lub stosowanie pulsacyjnych technik hydrostrumieniowych [18]. Stosowanie nowych hydrostrumieniowych metod przygotowania powierzchni wymaga zmiany poprzednich zasad, warunków i standardów Czyszczenia [10, 13], które zostały poparte przez wszechstronne opracowania kompromisowe [9] na poprzednich i nowych metodach obróbki powierzchni kadłubów statków. Trend procesu oczyszczania przez ultra wysokociśnieniowy czysty proces hydrostrumieniowy [14] zdominował otwierające się nowe perspektywy rozwoju [11, 16].

Oczyszczanie skorodowanych kadłubów statków wysokociśnieniowych technik hydrostrumieniowych jest nową, proekologiczną technologią, która obeznie intensywnie rozwija się. Główne trendy w rozwoju to automatyzacją i mechanizacją pracy oraz wzrost ciśnienia wody. Jednakże stosowanie nowych technologii w polskim przemyśle stoczniowym jest ograniczone z wielu powodów. Szczególnie dotyczy to małych stoczni, gdzie większość łodzi naprawia się ręcznie.

Technologie wprowadzane do tej pory w polskich stoczniach remontowych są nie tylko groźne dla środowiska ale co istotniejsze, wywołują tak zwane choróby zawodowe. Dotyczy to głównie usuwania korozji przy zastosowaniu nisko sprawnych metod piaskowania, która powoduje zanieczyszczenie powietrza w promieniu kilkuset metrów. W przeciwieństwie do tego, technologie hydrostrumieniowe bazujące na erozyjnych własnościach wody nie posiadają wymienionych wcześniej wad.

W artykule przedstawiono wysoko skuteczne urządzenia hydrostrumieniowe przeznaczone oczyszczania kadłubów wraz z ich gruntowną analizą. Dodatkowo przedstawiono przegląd najnowszego sprzętu wysokociśnieniowego oraz systemów, które są stosowane w stoczniach na całym świecie. Ten sprzęt i inne konstrukcje hydrostrumieniowe są stosowane i rozwijane w Centrum Technologicznym Niekonwencjonalnych Technologii Hydrostrumieniowych. Taka technologia zapewnia wysoką skuteczność i jest przyjazna dla środowiska.