Experimental procedure for the technical characterization of an innovative plant for seabed management in harbour’s areas

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Abstract

The main purpose of this paper is the description of the components and of the experimental procedure to be followed for the characterization of an innovative device, i.e. the ejector, for seabed management in harbour’s areas. The paper is divided in the following sections. After a brief overview of the state of the art in which criticalities of existing technologies are highlighted, a technical comparison is also performed respect to the technology developed by the Department of Industrial Engineering of the University of Bologna. In the second part of the paper, a detailed description of the main components and of the experimental procedure followed by test the device in the laboratory is reported. Lastly, conclusions about the experimental procedure are presented.

1. Introduction

Although traditional dredging is the commonly used solution for sediment management in coastal infrastructures, several critical issues require an alternative solution as soon as possible [*Boswood et al., 2001*]. In fact, environmental and economic considerations make dredging difficult or even prohibitive in some circumstances like small harbour’s entrances. In addition, an interruption of navigation or the reduction of tourism activities result during dredging such as also a high environmental impact on marine flora and fauna [*Erftemeijer et al., 2012; 2006*] due to the possible dispersion of contaminants and pollutants that are present in the seabed [*Vale et al., 1998; Bai et al., 2003*].

To overcome these lacks and to ensure seabed management in the desired conditions, the Department of Industrial Engineering of the University of Bologna developed an innovative device, called the ejector, able to maintain the desired level of the seabed, removing sediment at the port entrance and conveying it at a considerable distance without environmental impact. In fact, since the reduced speed of sea currents near to harbour’s infrastructure, sediments tend to settle down resulting in a reduction of the available seabed depth. Thanks to the proposed technology, instead, the sediments are conveyed away avoiding harbour’s activities interruption. Furthermore, because of the total mass balance of sediments is zero in stationary condition, no authorisation is mandatory as it is, instead, in case of traditional dredging [*Bianchini et al., 2014*].

2. Description of the innovative technology

As jet pumps, the ejector work principle is principally based on the momentum transfer from a high-speed primary flow to a secondary flow. However, several main differences are present between the two technologies. In particular, as shown in Figure 1, the ejector (right) has a different design respect to the traditional jet pump (left) such as 1) a converging section instead of a diffuser, 2) radial nozzles to ensure and to maximize the suspension of sediments and 3) the absence of a mixing zone due to the presence of an open section chamber [*Bianchini et al., 2014*].

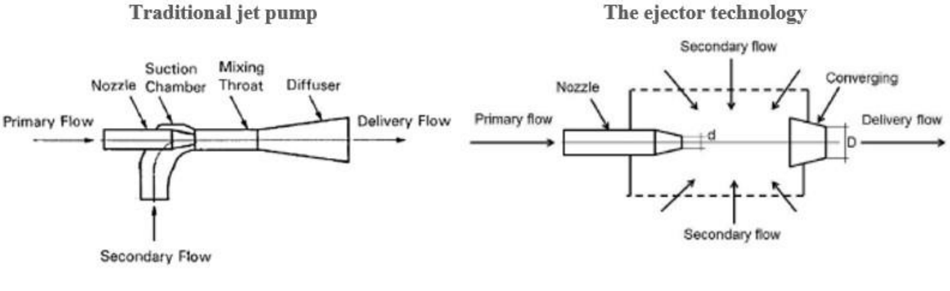


Figure 1. Design differences between a traditional jet pump and the ejector.

Concerning the working principle of the ejector, the primary fluid is conveyed by a pump entering into the ejector through the converging nozzle, where an increase of the dynamic pressure and a reduction of static pressure occur in accordance to the section reduction, so to Bernoulli's principle. As a result of the pressure reduction, a suspended mixture of sea water and sediments, produced by the high pressure sea water jets from radial nozzles, is sucked into the mixing chamber. Once mixed, the high momentum of the primary fluid is transferred to the secondary fluid characterized by a smaller momentum. Lastly, another converging section increases again the dynamic pressure to discharge the material at a certain distance from the ejector position overcoming the downstream duct pressure drop.

Compared to the other seabed solutions in literature, no moving parts or electrical cables are present minimising maintenance and thus operative costs. However, despite the simplicity of the ejector, plant auxiliaries such as, but not limited to pumps for the supply of marine water to the ejector, filters and other components such as valves for flow regulation or a sophisticated control system, are necessary for the correct operation of the innovative plant [*Bianchini et al., 2014*].

From an operational point of view, the ejectors can be both fixed and mobile even if the considerations of this paper are strictly valid for fixed ejectors. When used as a fixed device, an ejector operates on a limited area whose diameter depends on the characteristic of the sediment such as, for example, the rest angle. However, installing ejectors in series or in parallel a channel of passage can be realized [*Bianchini et al., 2013*].

3. Description of the components used during the laboratory experimental tests

The purpose of the test is to obtain the characteristic pressure and flow curves for the ejector as a function of different geometrical parameters such as 1) the diameter of the central convergent nozzle, 2) the distance between the converging nozzle, 3) the converging exhaust section and 4) the length of the downstream pipe. The simplified Piping and Instrumentation Design (P&ID) of the experimental test bench realized for the tests in the laboratory of Mechanics of the University of Bologna is shown in Figure 2.

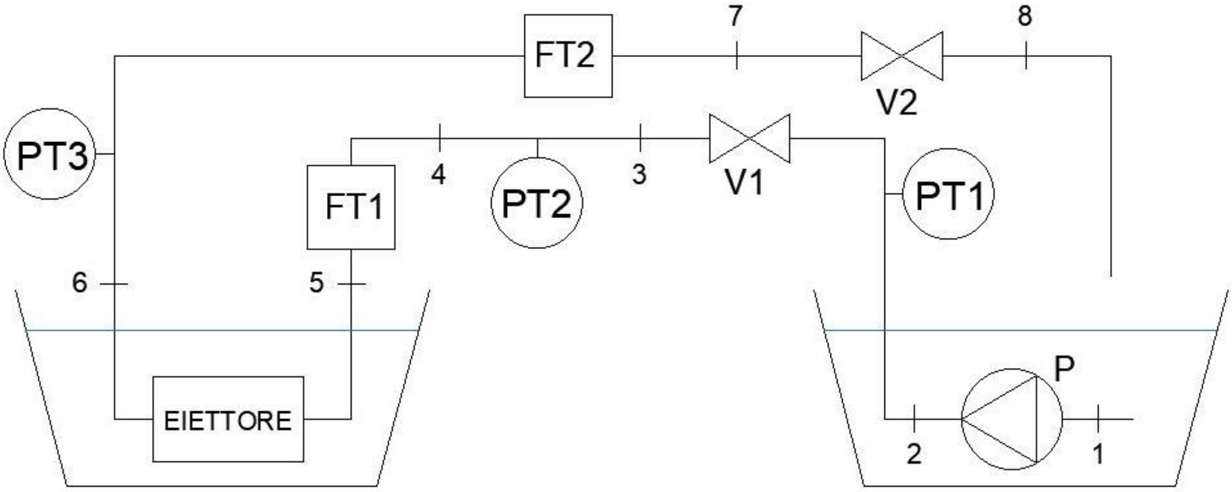


Figure 2. Piping & Instrumentation design of the experimental test bench. P = centrifugal pump; V = manual regulating valve; FT = Flow transducer; PT = Pressure transducer

The experimental plant consists of a closed circuit in which the water is taken from a tank (point 1 in the P&ID) and conveyed by a centrifugal pump to a second tank in which the ejector is present. The downstream pipe from the ejector is redirected again into the first tank (point 8). The 2 tanks, made of fibreglass, have a capacity of 1500 liters each. In order to inspect the submerged components during the tests, a plexiglas window was made in each vessel. The submerged borehole pump (P) used in the tests is a 3 kW type 2/40 Caprari Mec A centrifugal pump working at 2850 rpm, which characteristic curve is shown in Figure 3. A PVC tube with a nominal diameter of 3 inches is connected to the suction and a needled valve is installed (V1) at a distance of 0.9 m from the pump in a position easy to be adjusted during tests. Increasing or reducing the concentrated pressure drop through the valve, in fact, it is possible to change the characteristic curve of the circuit and so to regulate the water flowrate and the pressure at the suction of the ejector.

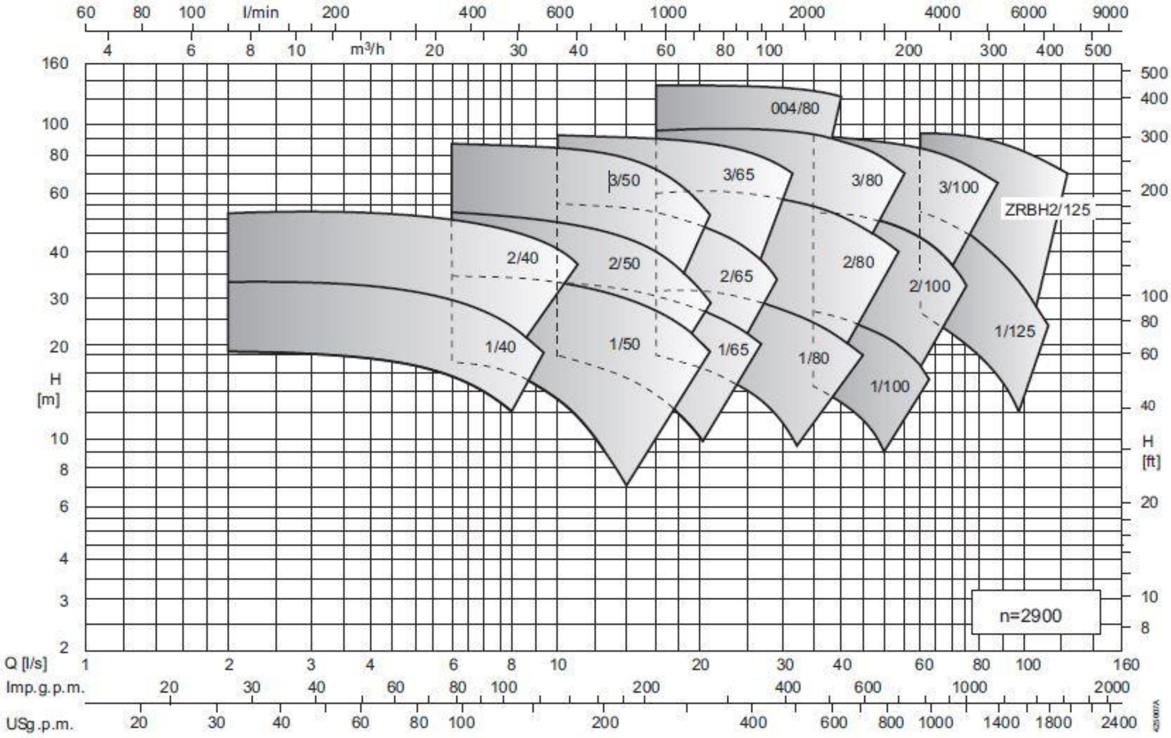


Figure 3. Test pump characteristic curves.

A digital absolute pressure transducer (PT1), model Cerabar PMC71 with oil-free ceramic sensor (see Table 1 for technical specifications), is installed to measure the pressure 1) downstream the pump (point 2), 2) after the valve V1 (point 3) and 3) downstream the ejector (point 6). These pressure measurements are essential in order to characterize the plant. However, since the installation of three transducers are not possible for economic reasons, the three points are connected to a manifold in which the Cerabar is installed. So pressure measurements are taken in different moments.

Table 1. Technical characteristics of the Cerabar PMC71.

Model	Cerabar PMC71
Producer	Endress + Hauser
Type of sensor	Ceramic
Type of measure	Absolute pressure
Operative range	0-10 bar
Span	0.1/10 bar
Maximum Working Pressure	26.7 bar
Accuracy	- TD from 1:1to 15:1: ±0.075% of span - TD > 15:1: ±0.005% of span

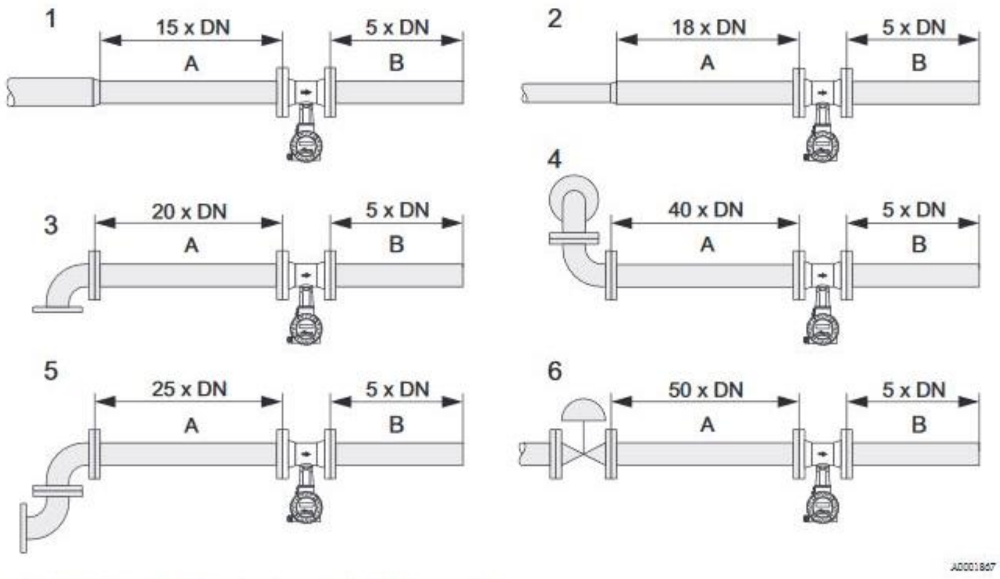
The flowrates upstream and downstream the ejector (point 5 and 7) are measured through two flow transducers (FT1 and FT2), Prowirl 73F1H model (the technical specifications are reported in Table 2). In particular, the water primary flow from the pump is conveyed through a 4 inch spiral PVC tube to the flow transducer. To respect ISO requirements, a length corresponding to 15 diameters before the meter and 5 diameters after it are taken (see Figure 5). At the end of the tube, a 3-inch spiral PVC pipe with a 3 m length is connected.

The same 3-inch spiral tube is connected at the ejector's delivery. Following at 4,20 m, a connection is inserted from which an absolute pressure point measurement (PT3) is carried out using the instrument reported in Table 1. Also in this case, distances to (FT2) Prowirl 73F1H are guaranteed connecting a 4-inch spiral tube.

Finally, a needle valve is installed with the aim to regulate the ejector back pressure. A spiral tube of 3 inches and length of 1.5m is connected to the valve discharging again the water in the first tank.

Table 2. Technical characteristics of the Prowirl 73F1H.

Model	Prowirl 73F1H
Producer	Endress + Hauser
Measuring principle	Vortex
Size	DN100
Nominal pressure	16 bar
k-factor	1.2769
Accuracy	- Re>20'000: <0.75% of the reading - Re between 4'000 e 20'000: <0.75% of the full range
Ripeatibility	±0.25% of the reading



Minimum inlet and outlet runs with various flow obstructions

A = Inlet run, B = Outlet run
1 = Reduction
2 = Extension
3 = 90° elbow or T-piece
4 = 2 x 90° elbow, 3-dimensional
5 = 2 x 90° elbow
6 = Control valve

Figure 4. Distance requirements before and after the flow transducer Prowirl 73F1H. Images from technical datasheet.

4. Experimental tests procedure

Experimental tests were carried out in the DIN laboratories from 2002 to 2013 analysing ejectors with different configurations and developing several geometries that were verified in the real environment. In particular, 1) different measurements of the diameter of the convergent nozzle, 2) different distances between the converging nozzle and the converging section, 3) different opening degrees of the V1 valve downstream of the centrifugal pump in order to assess the performance of the ejector at different feed pressure values and 4) different opening degrees of the V2 valve downstream of the flow meter to investigate different unloading conditions were tested in the test bench.

In fact, the operative performances of the ejector can be described by two dimensionless ratios, called respectively the flow ratio Q and the head ratio H in accordance to the following equations:

$$Q = \frac{Q_D}{Q_P} \qquad (1$$

$$H = \frac{H_D}{H_P} \qquad (2$$

where Q_P and H_P are respectively the flow rate and the pressure of the primary flow through the ejector, while Q_D and H_D are respectively the flow rate and the pressure exiting to the ejector.

An efficiency of the ejector η is also defined as the product between Q and H [*Bianchini et al., 2014*]:

$$\eta = Q \times H \qquad (3$$

Concerning the described test bench, H_P and H_D are directly measured by the pressure transducer at the sampling points PT2 and PT3, while the flow rates Q_P and Q_D are measured through the flow meters installed in suction and discharge pipes.

Closing or opening the needle valve (V1) downstream of the centrifugal pump (P), the pressure at ejector suction can be modified. Furthermore, by measuring the pressure drop between points 2 and 3 it is also possible to simulate a distributed pressure drops between the pump and the ejector with the concentrated pressure drop through the valve (V1).

In the same way, it is possible to simulate the distributed losses along the discharge pipe thanks to the downstream valve (V2). In this case the pressure upstream of the valve is calculated by means of the pressure transducer (PT3) while, leaving the tube free to discharge over the free hair of the tank, the downstream pressure is calculated considering the discharge at the atmospheric pressure.

5. Conclusions

In conclusion, the designed test bench allows to obtain the characteristic curves and therefore to compare different ejector's configurations. During laboratory tests ejectors with different measurements of the diameter of the convergent nozzle, different distances between the converging nozzle and the converging section were characterized simply calculating two adimensional parameters, i.e. the flow and the head rations.

Different working conditions in the fields were simulated installing in the circuit needle valve able to simulate distributed pressure drops. In particular, different distances between the pump and the ejectors as between the ejectors and the discharge point were tested. It resulted that beyond a limit value for valve V2 closure (corresponding to an increase in the length of the discharge pipe) the pressure drop was so high to not guarantee the minimum flow to discharge the mixture of water and sediments.

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