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EFFECT OF THE HEIGHT OF THE DELIVERY WATER ON PERFORMANCE OF WATER RAM

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Key words: ram water, test stand, equations of performance.

Abstract

The main aim of this article is to develop mathematical equations of the performance stream ($\dot{V}_c$) of a water ram with regard to the height of water delivery (h_c). The study was performed on the sample water ram of my own design mounted on a specially designed test stand. The content of the article is divided into two parts. The first part describes a generalized equation on the base formulae used historically to determine the performance of the water ram. The second part presents the results of research and summarizes the mathematical equations determining the streams performance ($\dot{V}_c$) according to the height of water delivery (h_c). In conclusion the article makes interpretations of the results. The motivation to approach these issues stems from the question: How much will the performance of the water ram has on the ability to set a receiver tank at different heights?

Introduction

The water ram is a kind of water pump to lift water to higher levels (H_d) than the height of the water source (H) (Fig. 1). The ram pump action is based on the use of kinetic energy of water flowing through the device. The water supply source can be any flow for example: river, stream, lake, etc. It is only important that the flow must provide adequate water ($Q + Q_w$), to create an appropriate water hammer necessary to further correct its work (MOHAMMED 2007, CLARKE 1900, WATT 1975).

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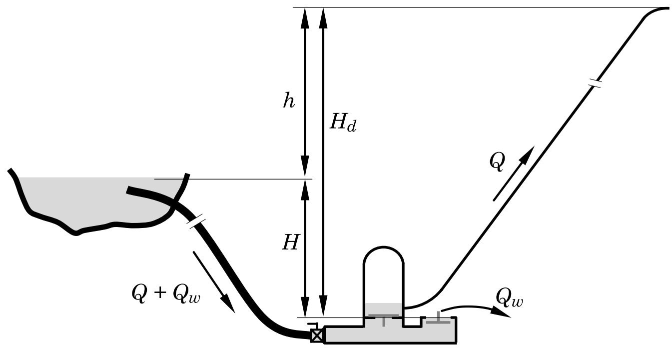

Fig. 1. Scheme of water ram describes Rankine and D'Aubuisson methods

Analyzing the history of water rams can find information about their efficiency. The efficiency can be described by the following methods (TAYE 1998, MOHAMMED 2007, WATT 1975, LANSFORD, DUGAN 1941, JONG 2015, CALHOUN 2003, DERKOR 2014, ZOLLER 2015, CLARKE 1900, MARUCHIN, KUTIENKOW 2014):

– Rankine method:

$$E = \frac{Q \cdot H_d}{(Q + Q_w) \cdot H} \tag{1}$$

– D'Aubuisson

$$E = \frac{Q \cdot h}{(Q + Q_w) \cdot H} \tag{2}$$

where:

E – is the efficiency of the hydram,
Q – is the pumped flow [l/min],
Q_w – is the wasted flow [l/min],
h – is the pump head above the source [m],
H – is the supply head above the waste valve opening [m],
H_d – is the total head above the waste valve opening = $(H+h)$ [m].

The main aim of this work is to define the mathematical relationship that makes it possible to determine the impact of the delivery height of the water (H_d) on the performance (Q) of the water ram (Fig. 1).

Other relationships allow for an accurate calculation of the performance (Q) of the water ram and all of its opportunities to lift water taking into account parameters such as: the volume of the air chamber, the height of the water source (H_d) and the height of water delivery (H) described in detail in part one of a series of articles about water rams, GRYGO D. et al.: *Performance characteristics of water rams*. The study was performed on a simple water ram of my own design mounted on a specially designed test stand.

The motivation for the study is to improve machinery and equipment so that their action is based on unconventionally by using renewable energy for devices that can be used in the household e.g. to improve its energy balance, free delivery of water, land irrigation, the watering of animals, etc.

The work presented the results of performance and mathematical equations of performance for three options: 1. h_s = 5 m, 2. h_s = 4 m, 3. h_s = 3 m (see Fig. 2). The summary presents the interpretation of these results.

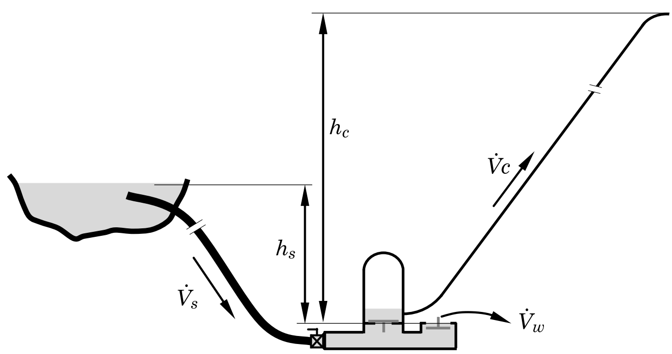

Fig. 2. Installation scheme of water ram

Performance equations

Performance measurements of the water ram were carried out for three heights of different water supply (3, 4 and 5 m) and for eight ranges of water lifting (in ranges of 5 to 16 m). For each configuration three measurements were made. The performance was determined by the „mass flow" rate method. The method of mass flow rates was selected due to high accuracy and a short measuring time.

To measure the amount (weight) of water collected in holding tanks (*1* and *2*) (Fig. 3) the measuring system uses a force sensor Axis type FA200 (*3* and *4*) with the maximum rate measuring 200 [N] (~ 20 kg) with a measurement accuracy of ±0.05. Following suspension of the holding tanks the sensors were reset so as to indicate only the weight of the water. Knowing the weight of water accumulated in holding tanks and its temperature determined its mass. The water temperature was measured by an electronic sensor with an accuracy of 0.1°C.

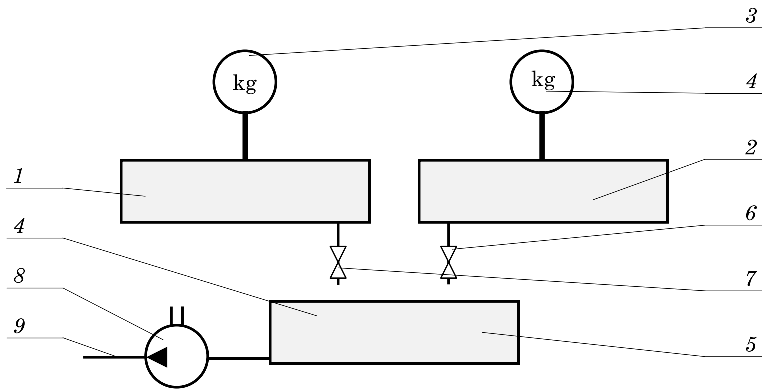

Fig. 3. The measuring system

For this purpose, an electronic thermometer was used with readout system of internal and external temperatures by means of a probe. A thermometer was placed in a shaded area approximately 0.5 m of the water tank and the probe placed inside the tank.

The water ram worked for measurement for about 15 minutes. At this time the impulse valve was regulated to obtain the stability of all the system parameters. After this period a redirection the outflow water ($\dot{V}_w$ and $\dot{V}_c$), according to the measuring tanks (*1* and *2*) was made. The water collected for 180 s, over time delivered volume readings. After readings valves were opened (*6* and *7*) and the water flowed into the tank (*5*). From there via the electric water pump (*8*) to the main supply tank. It was important to mount the electric pump so that the amount of water in the system was constant. The settings of the parameters were as follows: h_s = 3, 4 and 5 m, the temperature was 15.0°C and the volume of the air chamber of the water ram was 3 dm^3. In Table 1, 2 and 3 the average results of three measurements are shown. Figures 4, 5 and 6 show the water flow rate in graphical form for a particular configuration and in Figures 7, 8 and 9 show mathematical equations in a graphical form.

Table 1

Measurement results h_s = 5 [m]

h_c [m]	$\dot{V}_c$ [dm^3/180 s]
10	2.856
11	2.239
12	1.480
13	0.677

Table 2

Measurement results h_s = 4 [m]

h_c [m]	q_c [dm^3/180 s]
10	2.829
11	2.290
12	1.453
13	1.425
14	0.844

Table 3

Measurement results h_s = 3 [m]

h_c [m]	q_c [dm^3/180 s]
6	3.532
7	3.386
8	2.834
9	2.093
10	1.618
11	1.238
12	0.369

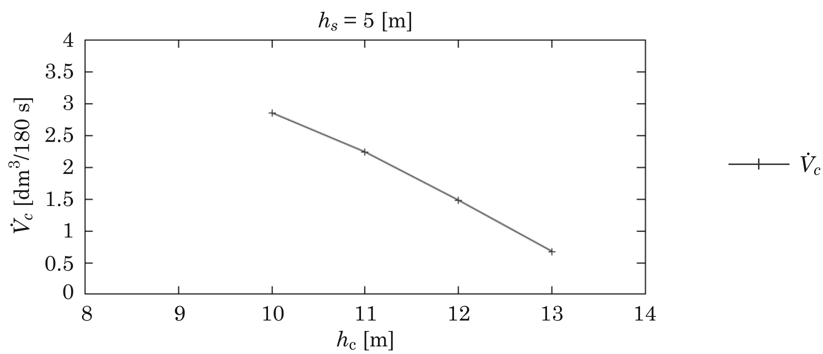

Fig. 4. The stream of water flow rate for h_s = 5 m

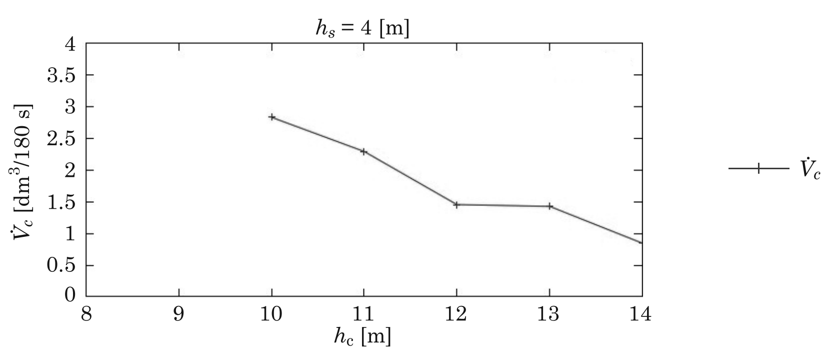

Fig. 5. The stream of water flow rate for h_s = 4 m

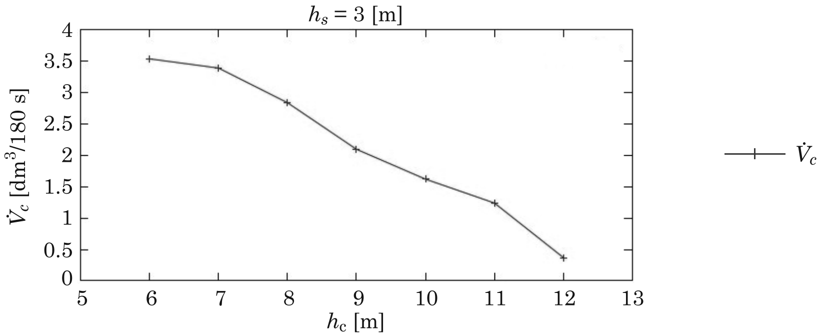

Fig. 6. The stream of water flow rate for $h_s = 3$ m

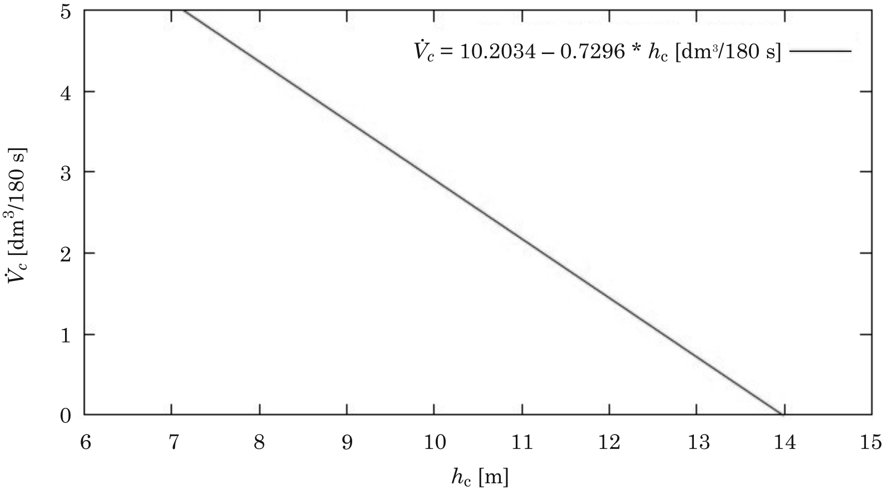

Fig. 7. The regression equation graph 6

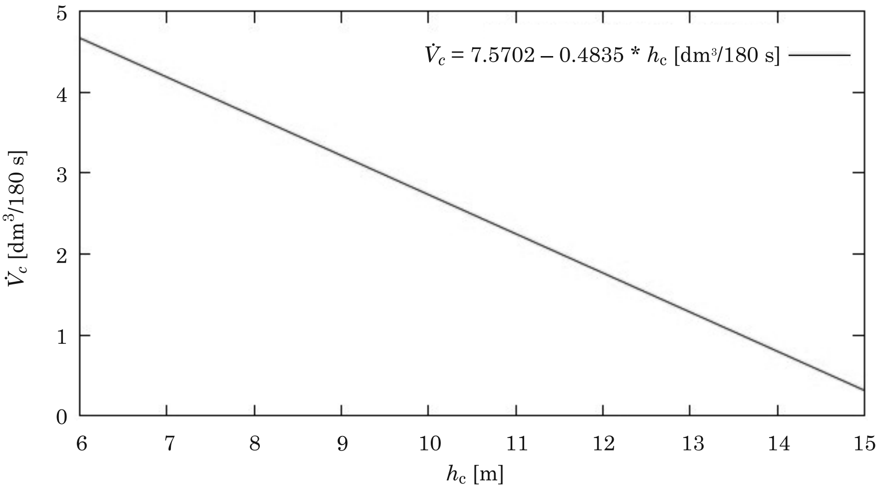

Fig. 8. The regression equation graph 7

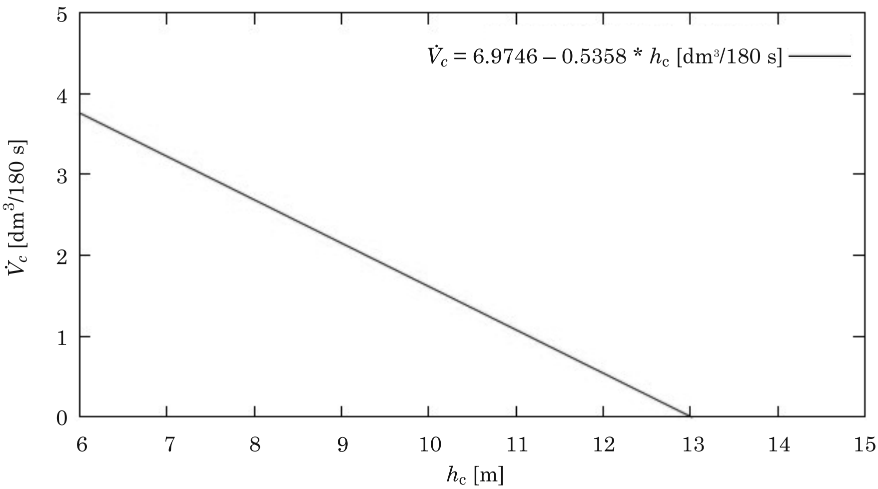

Fig. 9. The regression equation graph 8

The results were verified statistically using regression analysis. The regression analysis was used to determine the nature of the relationship between the dependent variable ($\dot{V}_c$) and the independent variable (h_c) for stochastic models describing the relationship:

$$\dot{V}_c = f(h_s) \tag{3}$$

was selected using the regression line (RABIEJ 2012, LUSZCZEWICZ, SLABY 2008). Guided by the principle that physical relationships often occur in simple mathematical forms (PRZESTALSKI 2009) and that reality can be successfully described by several models (OSOWSKI 2007), tested the function of the following forms:

$$Y = \xi_0 + \xi_1 X_1 + \xi_2 X_2 + \xi_3 X_3 \tag{4}$$

for the calculation of statistical procedures, I used package Statistica PL. v10 (STANISZ 2007). The hypotheses verified H_0, that the structural parameters of the equation were insignificantly different at zero ($\alpha_i = 0$). In a case where $p(F) \geq \alpha$ there was no reason to reject the hypotheses H_0 and when $p(F) < \alpha$ rejected in a favor of the alternative hypotheses H_1 ($\alpha_i \neq 0$). The results of the statistical calculations and regression equations shown in the appropriate Tables 2, 4 and 6.

Table 4

The results $h_s = 5$ m

Variable	Average value	Standard deviation	The coefficient of variation [%]
Lift height water h_c [m]	11.50	1.118034	9.72
Water flow rate $\dot{V}_c$ [m^3/180 s]	1.81	0.817115	45.07

Verification of the hypothesis about the significance of the coefficients of regression equations
H_0: The regression coefficients are zero
H_1: Not all of the regression coefficients are equal to zero
Test results:

The percentage of variation explained	99.66
Multiple correlation coefficient	0.998
The standard deviation of the residues	0.067562

The critical region right-hand
The level of significance = 0.05
The calculated value of statistics $F_{(1;2)} = 583.0918$
The level of probability test $p = 0.0017$
H_0 should be rejected in favor of the alternative hypothesis H_1

Table 5

The results $h_s = 4$ m

Variable	Average value	Standard deviation	The coefficient of variation [%]
Lift height water h_c [m]	12.00	1.414214	11.79
Water flow rate $\dot{V}_c$ [m^3/180 s]	1.77	0.7002688	39.74

Verification of the hypothesis about the significance of the coefficients of regression equations
H_0: The regression coefficients are zero
H_1: Not all of the regression coefficients are equal to zero
Test results:

The percentage of variation explained	94.69
Multiple correlation coefficient	0.973
The standard deviation of the residues	0.209071

The critical region right-hand
The level of significance = 0.05
The calculated value of statistics $F_{(1;3)} = 53.4816$
The level of probability test $p = 0.0053$
H_0 should be rejected in favor of the alternative hypothesis H_1

Table 6

The results h_s = 3 m

Variable	Average value	Standard deviation	The coefficient of variation [%]
Lift height water h_c [m]	9.00	2.000000	22.22
Water flow rate $\dot{V}_c$ [m^3/180 s]	2.15	1.082022	50.26

Verification of the hypothesis about the significance of the coefficients of regression equations
H_0: The regression coefficients are zero
H_1: Not all of the regression coefficients are equal to zero
Test results:

The percentage of variation explained	98.06
Multiple correlation coefficient	0.99
The standard deviation of the residues	0.178107

The critical region right-hand
The level of significance = 0.05
The calculated value of statistics $F_{(1;5)}$ = 253.3488
The level of probability test p = 0.0000
H_0 should be rejected in favor of the alternative hypothesis H_1

The equation of performance (h_s = 5 m)

The linear regression. General information: number of observations = 4, adopted significance level = 0.05.

The regression equation:

$$\dot{V}_c = 10.2034 - 0.7296 \cdot h_c \quad (5)$$

The equation of performance (h_s = 4 m)

The linear regression. General information: number of observations = 5, adopted significance level = 0.05.

The regression equation:

$$\dot{V}_c = 7.5702 - 0.4835 \cdot h_c \quad (6)$$

The equation of performance (h_s = 3 m)

The linear regression. General information: number of observations = 7, adopted significance level = 0.05.

The regression equation:

$$\dot{V}_c = 6.9746 - 0.5358 \cdot h_c \quad (7)$$

Summary

The main aim of this work is to define the mathematical relationship that allows determination of the impact of the height of water (h_c) on the performance ($\dot{V}_c$) of water ram. Analyzing the results obtained during the performance of the test it was able to determine the equation of variation of functions for each specified of height of delivery. The first model (h_c = 5 m) is the most suited (99.66 percent of the explained variations) while two other models have proved to be well matched (94.69 and 98.06 percent of the explained variations). It was shown that the relationship for the model:

– First, that at the average height of water delivery (h_c) equals 11.5 m the performance is 1.81 dm^3/180 s. From the obtained mathematical data (regression equation) shows that by increasing the height of water delivery by 1 m will reduce the performance about 0.7296 dm^3/180 s and will be equal to 1.08 dm^3/180 s;

– Second, that at the average height of water delivery (h_c) equals 12.0 [m] the performance is 1.77 dm^3/180 s. From the obtained mathematical dependence (regression equation) it shows that by increasing the height of water delivery by 1 [m] it will reduce performance of 0.4835 dm^3/180 s and will be equal to 1.29 dm^3/180 s;

– Third, that at the average height of water delivery (h_c) equals 9.0 m the performance is 2.15 dm^3/180 s. From the obtained mathematical dependence (regression equation) it shows that by increasing the height of water delivery by 1 m it will reduce the performance by 0.5358 dm^3/180 s and will be equal to 1.62 dm^3/180 s.

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