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The Hill Chart Calculation for Pelton Runner Models using the HydroHillChart - Pelton Module Software

The Pelton turbines industrial design is based on the hill chart characteristics obtained by measuring the models. Primary data measurements used to obtain the hill chart can be processed graphically, by hand or by using graphic programs respectively CAD programs; the HydroHillChart - Pelton module software is a specialized tool in achieving the hill chart, using interpolation cubic spline functions. Thereby, based on measurements of several models of Pelton turbines, a computerized library, used to design industrial Pelton turbines can be created. The paper presents the universal characteristics calculated by using the HydroHillChart - Pelton module software for a series of Pelton runners.

Keywords*: turbine, runner, Pelton, hill chart*

1. Introduction

The **HydroHillChart** application was created using the Python programming language and its associated modules [1]. The Pelton module is an integral part of this application and allows the hill chart calculation for Pelton runners, based on measurements of the model.

Using the **HydroHillChart - Pelton module** software, the hill chart for the following models of Pelton runners will be drawn:

- V2 runner with a diameter D = 148 mm, 19 buckets and nozzle / needle injector with a diameter of Ø16.3 mm (www.csnp.roedu.ro/rotor_pelton2.htm); input data was taken from measurements performed on the model [2];

- K461 runner with a diameter D = 450 mm, 20 buckets and 6 injectors with Ø47.25 mm in diameter [3];

For the K461 runner, the input data was taken from literature as discrete points of the existing characteristics [3] in order to compare them with the characteristics calculated by the **HydroHillChart - Pelton module** software.

The input data required by the **HydroHillChart - Pelton module** software are as follows:

- **ID punct** - serial number of the measuring point;

- **S** [mm] - injector needle opening for Pelton runner;
- **Q_{11}** [m3/s] - unitary flow;
- **n_{11}** [rot/min] - unitary speed;
- **η** [%] – efficiency.

2. The calculation of the hill chart for V2-16.3 runner

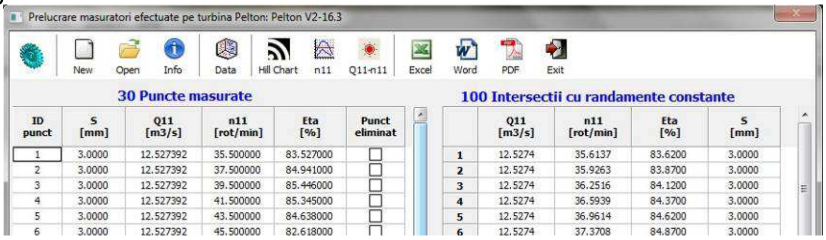
The input data for V2-16.3 runner is presented in Table 1.

Table 1.

ID punct	S [mm]	Q_{11} [m3/s]	n_{11} [rot/min]	η [%]	ID punct	S [mm]	Q_{11} [m3/s]	n_{11} [rot/min]	η [%]
1	3	12.527	35.5	83.527	16	9	23.290	41.5	90.092
2	3	12.527	37.5	84.941	17	9	23.290	43.5	88.981
3	3	12.527	39.5	85.446	18	9	23.290	45.5	86.456
4	3	12.527	41.5	85.345	19	12	26.983	35.5	87.769
5	3	12.527	43.5	84.638	20	12	26.983	37.5	88.981
6	3	12.527	45.5	82.618	21	12	26.983	39.5	89.789
7	6	18.541	35.5	87.668	22	12	26.983	41.5	89.688
8	6	18.541	37.5	88.678	23	12	26.983	43.5	88.577
9	6	18.541	39.5	89.284	24	12	26.983	45.5	86.254
10	6	18.541	41.5	89.183	25	15	29.419	35.5	87.163
11	6	18.541	43.5	88.274	26	15	29.419	37.5	88.173
12	6	18.541	45.5	86.052	27	15	29.419	39.5	88.779
13	9	23.290	35.5	87.870	28	15	29.419	41.5	88.779
14	9	23.290	37.5	89.183	29	15	29.419	43.5	87.870
15	9	23.290	39.5	90.092	30	15	29.419	45.5	85.749

For the V2-16.3 runner in the **Puncte măsurate** table, input data was taken from Excel and it leads to a total of 30 points, Figure 1. In this table, the **Punct eliminat** column allows the removal of a point, by activating a **Check Box** control type. Measurements were performed for five constant openings of the needle injector: S=3, 6, 9, 12, 15 mm. $\eta = f(n_{11})$ primary curves, obtained from measured data for each opening of the needle injector are shown in Figures 2÷6, wherein the measured points are marked by circles, and Figure 7 shows the correlation $S = f(Q_{11})$. Figure 8 and Figure 9 show the superimposed $\eta = f(n_{11})$ 2D curves and $\eta = f(n_{11}, Q_{11})$ 3D curves for the S parameter values.

For the V2-16.3 runner, the efficiency values η are fitted between 82.62 and 90.09%. The hill chart was calculated for 30 values imposed in the η =82.75 ÷ 90% domain with a step of 0.25%. The $\eta = f(n_{11}, Q_{11})$ surface that intersects with the constant efficiency values is shown in figure 10; from these intersections, the points of the table **Intersectii cu randamente constante**, Figure 10, the 3D intersection curves, Figure 11 and the hill chart, Figure 12 arise. Intersection points with constant efficiency values are also marked with triangles in the interpolated primary curve from Figures 2 ÷ 6.



Prelucrare masuratori efectuate pe turbina Pelton: Pelton V2-16.3

New Open Info Data Hill Chart n11 Q11-n11 Excel Word PDF Exit

30 Puncte masurate

ID punct	S [mm]	Q11 [m3/s]	n11 [rot/min]	Eta [%]	Punct eliminat
1	3.0000	12.527392	35.500000	83.527000	☐
2	3.0000	12.527392	37.500000	84.941000	☐
3	3.0000	12.527392	39.500000	85.446000	☐
4	3.0000	12.527392	41.500000	85.345000	☐
5	3.0000	12.527392	43.500000	84.638000	☐
6	3.0000	12.527392	45.500000	82.618000	☐

100 Intersectii cu randamente constante

	Q11 [m3/s]	n11 [rot/min]	Eta [%]	S [mm]
1	12.5274	35.6137	83.6200	3.0000
2	12.5274	35.9263	83.8700	3.0000
3	12.5274	36.2516	84.1200	3.0000
4	12.5274	36.5939	84.3700	3.0000
5	12.5274	36.9614	84.6200	3.0000
6	12.5274	37.3708	84.8700	3.0000

Figure 1. Table **Puncte măsurate** for V2-16.3 runner

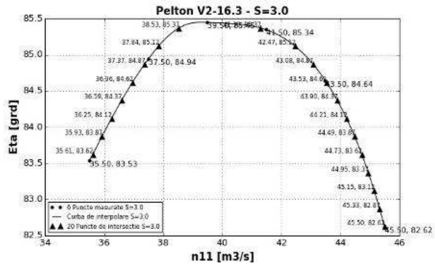


Figure 2. $\eta = f(n_{11})$ primary curve for S=3 mm, V2-16.3 runner

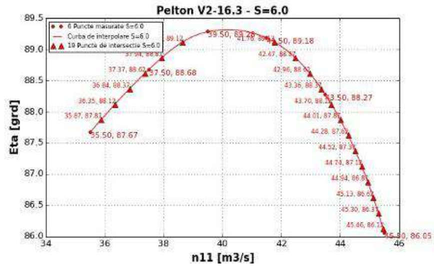


Figure 3. $\eta = f(n_{11})$ primary curve for S=6 mm, V2-16.3 runner

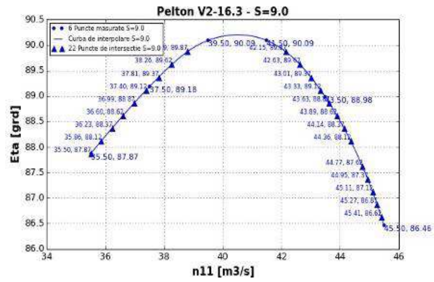


Figure 4. $\eta = f(n_{11})$ primary curve for S=9 mm, V2-16.3 runner

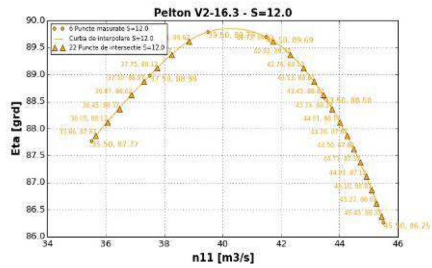


Figure 5. $\eta = f(n_{11})$ primary curve for S=12 mm, V2-16.3 runner

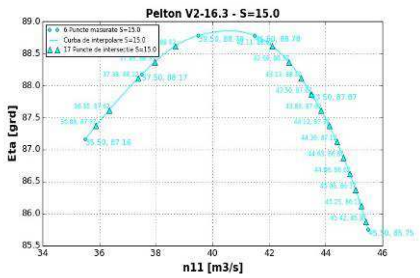


Figure 6. $\eta = f(n_{11})$ primary curve for S=15 mm, V2-16.3 runner

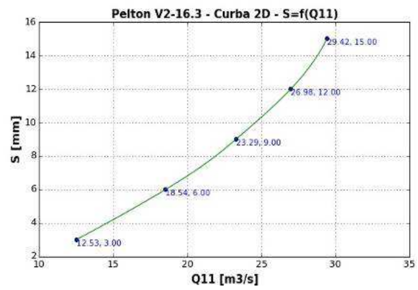


Figure 7. $S = f(Q_{11})$ primary curve for V2-16.3 runner

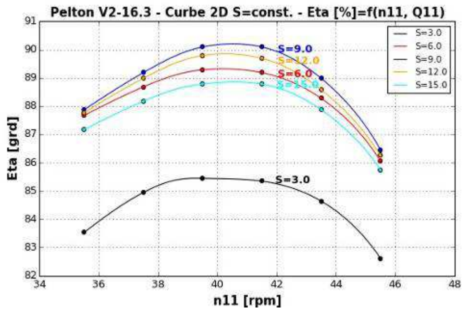


Figure 8. $\eta = f(n_{11})$ 2D Curves for S parameter - V2-16.3 Pelton runner

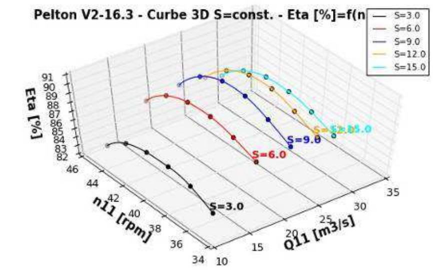


Figure 9. $\eta = f(n_{11}, Q_{11})$ 3D curves for V2-16.3 Pelton runner

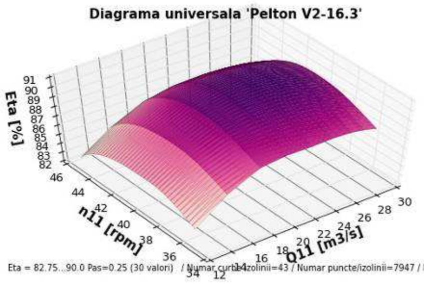


Figure 10. $\eta = f(n_{11}, Q_{11})$ 3D surface for V2-16.3 Pelton runner

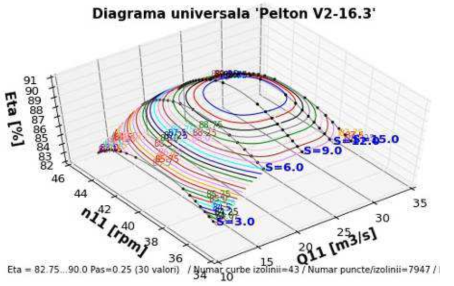


Figure 11. 3D intersection curves with constant efficiency - V2-16.3 Pelton runner

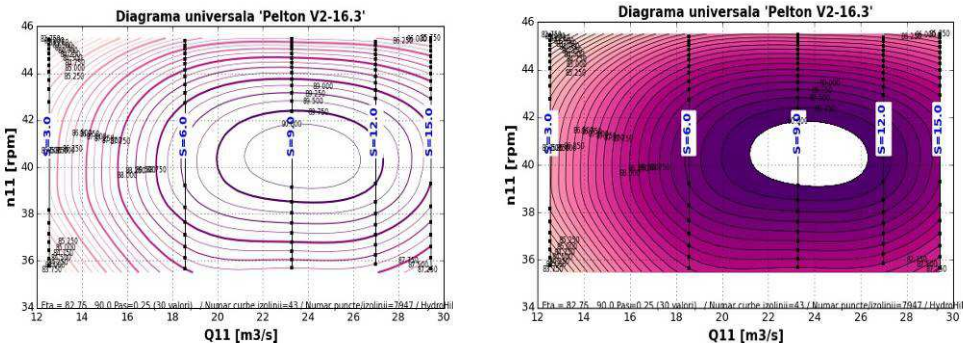


Figure 12. Universal characteristic for V2-16.3 Pelton runner

The **HydroHillChart - Pelton** module software also allows:

- the intersection of a universal characteristic with a required constant unitary speed $\mathbf{n_{11}}$;
- efficiency calculation for a required $\mathbf{n_{11}}$-$\mathbf{Q_{11}}$ point.

For the V2-16.3 runner, for example, a unitary speed of $n_{11} = 40.0\,rpm$ was imposed, for which 2D curves: $\eta = f(Q_{11})$ and $\eta = f(S)$, Figure 13 and 14, respectively $\eta = f(n_{11}, Q_{11})$ 3D curves including intersection curve, Figure 15 have been calculated/plotted. The calculated efficiency for a unitary speed n_{11}=38.0 rpm and unitary flow Q_{11}=20.0 m^3/s is 89.45%. $\eta = f(n_{11}, Q_{11})$ 3D curves and the intersection point for the required unitary speed and flow are shown in Figure 16, respectively $\eta = f(Q_{11})$ and $\eta = f(S)$ 2D curves in Figures 17 and 18.

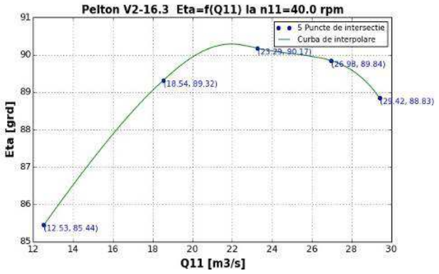


Figure 13. $\eta = f(Q_{11})$ 2D curve for n_{11}=40.0 rpm - V2-16.3 Pelton runner

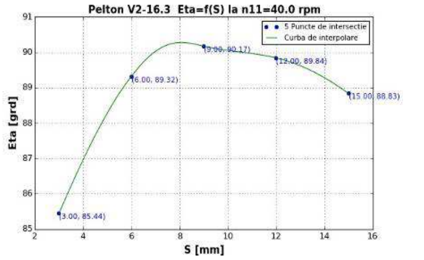


Figure 14. $\eta = f(S)$ 2D curve for n_{11}=40.0 rpm - V2-16.3 Pelton runner

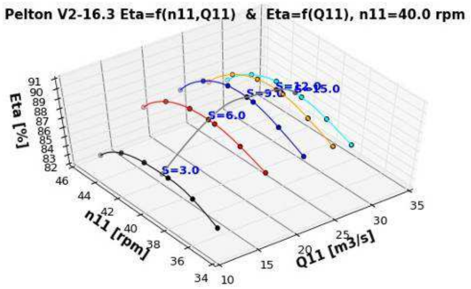


Figure 15. $\eta = f(n_{11}, Q_{11})$ 3D curves for n_{11}=40.0 rpm and the intersection curve $\eta = f(Q_{11})$ - V2-16.3 Pelton runner

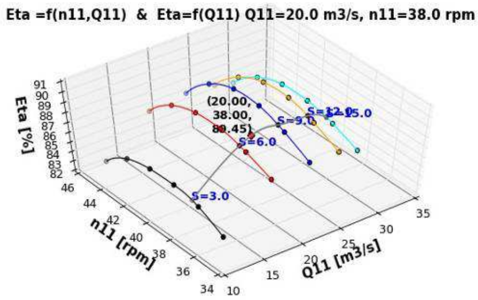


Figure 16. $\eta = f(n_{11}, Q_{11})$ 3D curves for Q_{11}=20.0 m^3/s and n_{11}=38 rpm, curve and the point of intersection - V2-16.3 Pelton runner

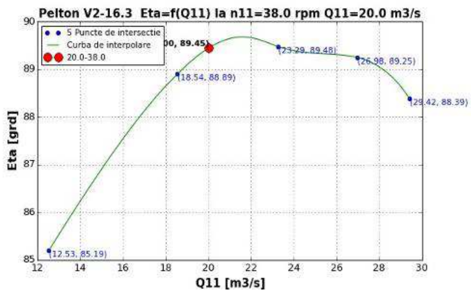


Figure 17. $\eta = f(Q_{11})$ 2D curve for n_{11}=38 rpm and Q_{11}=20.0 m^3/s, the point of intersection - V2-16.3 Pelton runner

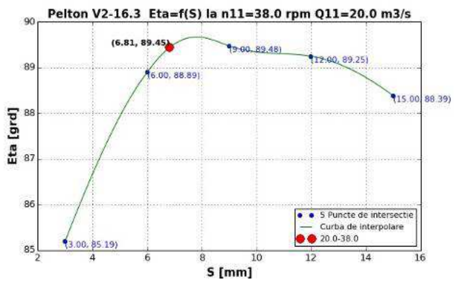


Figure 18. $\eta = f(S)$ 2D curve for n_{11}=38 rpm and Q_{11}=20.0 m^3/s, the point of intersection - V2-16.3 Pelton runner

Numerical and graphical results for a V2-16.3 runner can be exported in an Excel file, tabs **Date măsurate**, Figure 19, **Intersecții**, Figure 20 and respectively **HillChart**, Figure 21.

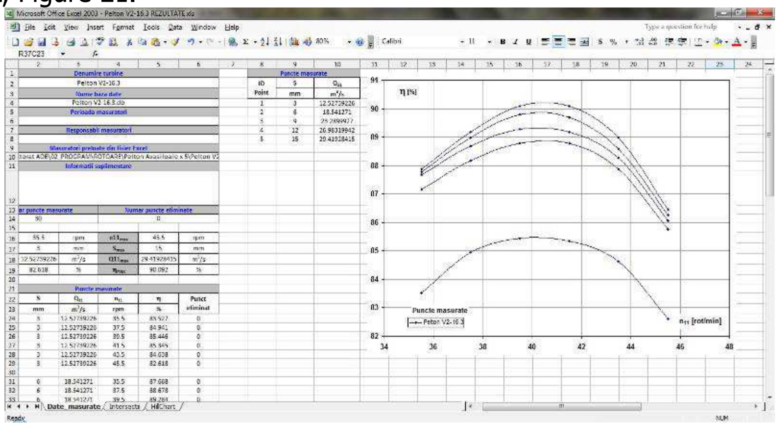


Figure 19. The **Date măsurate** sheet from Excel file - V2-16.3 runner

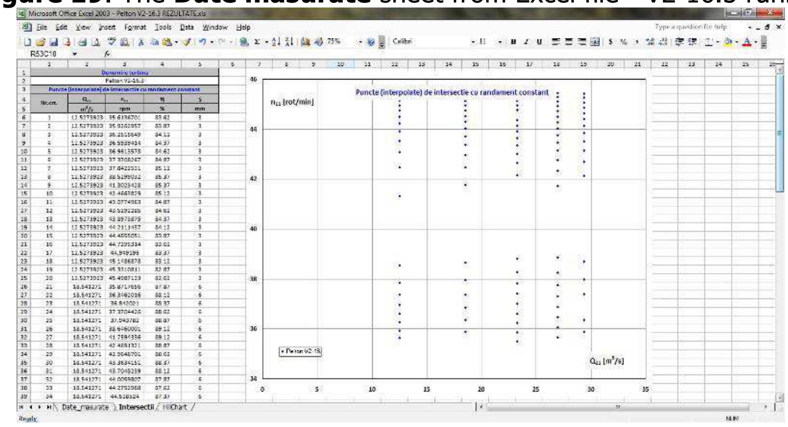


Figure 20. The **Intersecții** sheet from Excel file - V2-16.3 runner

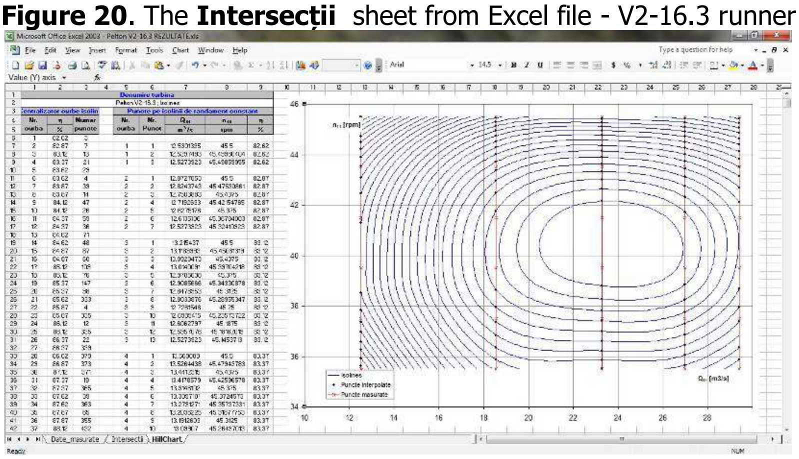


Figure 21. The **HillChart** sheet from Excel file - V2-16.3 runner

3. The calculation of the universal characteristics for a K461 runner

For a K461 runner, input data was taken from [3], page 98, as discrete points of the existing hill chart, Figure 22 and Table 2, in order to recalculate it by using the **HydroHillChart** - Pelton module software. For the K461 runner, input data was taken from Excel, totaling 51 points in the **Puncte măsurate** table. Measurements were performed for six constant openings of the needle injector: S=7.5, 10, 15, 20, 30, 40 mm. $\eta = f(n_{11})$ primary curves, obtained from the measured data for each opening of the needle injector, are shown in Figures 23÷28, wherein the measured points are marked by circles. Figure 29 and 30 show the superimposed $\eta = f(n_{11})$ 2D curves and $\eta = f(n_{11}, Q_{11})$ 3D curves for the S parameter values.

For the K461 runner, the efficiency values domain η is fitted between 73 and 88.9%. The hill chart was calculated for 32 values, imposed in the η =73 ÷ 88.5% domain with a step of 0.5%. The $\eta = f(n_{11}, Q_{11})$ surface that intersects with the constant efficiency values is shown in figure 31; from these intersections, the points of intersection, Figure 10, the 3D intersection curves, Figure 32 and the hill chart, Figure 33 arise. Intersection points with constant efficiency are also marked with triangles in the interpolated primary curve from Figures 23 ÷ 28.

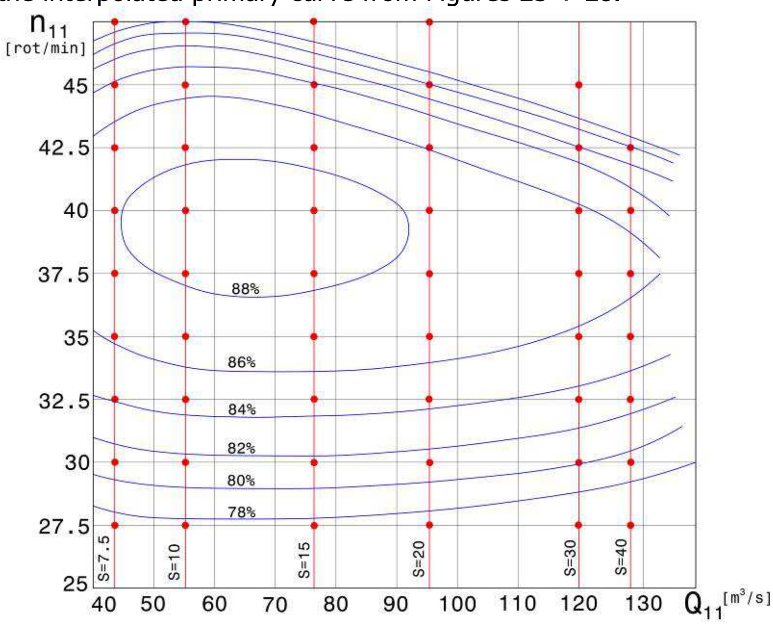


Figure 22. The K461 runner hill chart and the matrix of discrete points

Input data for the K461 Pelton runner is presented in Table 2.

Table 2.

ID punct	S [mm]	Q_{11} [m3/s]	n_{11} [rot/min]	η [%]	ID punct	S [mm]	Q_{11} [m3/s]	n_{11} [rot/min]	η [%]
1	7.5	43.75	27.5	77.40	27	15.0	77.50	47.5	76.50
2	7.5	43.75	30	81.00	28	20.0	96.25	27.5	77.10
3	7.5	43.75	32.5	84.00	29	20.0	96.25	30	81.00
4	7.5	43.75	35	86.20	30	20.0	96.25	32.5	84.30
5	7.5	43.75	37.5	87.50	31	20.0	96.25	35	86.60
6	7.5	43.75	40	87.80	32	20.0	96.25	37.5	87.80
7	7.5	43.75	42.5	86.80	33	20.0	96.25	40	87.60
8	7.5	43.75	45	83.20	34	20.0	96.25	42.5	85.50
9	7.5	43.75	47.5	78.00	35	20.0	96.25	45	80.20
10	10.0	56.00	27.5	77.60	36	20.0	96.25	47.5	73.00
11	10.0	56.00	30	81.30	37	30.0	119.00	27.5	76.00
12	10.0	56.00	32.5	84.40	38	30.0	119.00	30	80.00
13	10.0	56.00	35	86.70	39	30.0	119.00	32.5	83.50
14	10.0	56.00	37.5	88.30	40	30.0	119.00	35	85.80
15	10.0	56.00	40	88.90	41	30.0	119.00	37.5	87.00
16	10.0	56.00	42.5	87.90	42	30.0	119.00	40	85.70
17	10.0	56.00	45	84.20	43	30.0	119.00	42.5	81.00
18	10.0	56.00	47.5	78.50	44	30.0	119.00	45	75.00
19	15.0	77.50	27.5	77.60	45	40.0	129.00	27.5	75.00
20	15.0	77.50	30	81.40	46	40.0	129.00	30	79.00
21	15.0	77.50	32.5	84.70	47	40.0	129.00	32.5	82.50
22	15.0	77.50	35	86.90	48	40.0	129.00	35	85.00
23	15.0	77.50	37.5	88.30	49	40.0	129.00	37.5	86.10
24	15.0	77.50	40	88.50	50	40.0	129.00	40	84.00
25	15.0	77.50	42.5	87.00	51	40.0	129.00	42.5	80.00
26	15.0	77.50	45	82.60					

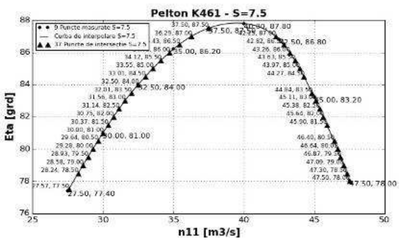


Figure 23. $\eta = f(n_{11})$ primary curve for S=7.5 mm - K461 Pelton runner

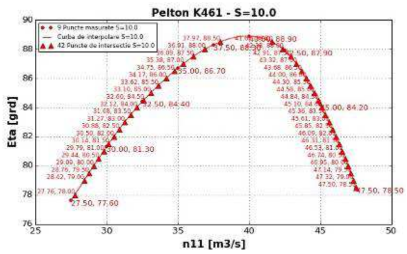


Figure 24. $\eta = f(n_{11})$ primary curve for S=10 mm - K461 Pelton runner

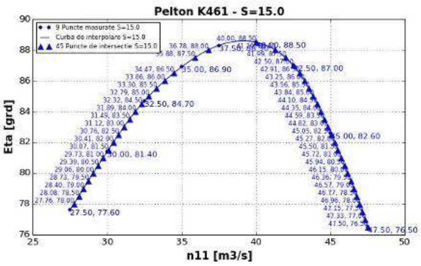


Figure 25. $\eta = f(n_{11})$ primary curve for S=15 mm - K461 Pelton runner

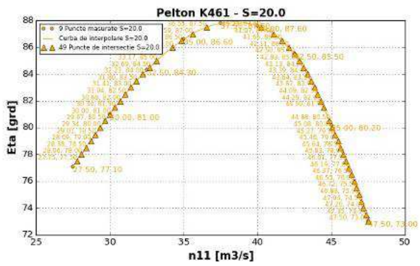


Figure 26. $\eta = f(n_{11})$ primary curve for S=20 mm - K461 Pelton runner

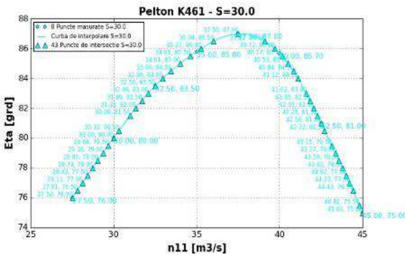


Figure 27. $\eta = f(n_{11})$ primary curve for S=30 mm - K461 Pelton runner

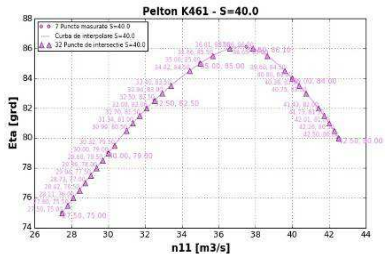


Figure 28. $\eta = f(n_{11})$ primary curve for S=40 mm - K461 Pelton runner

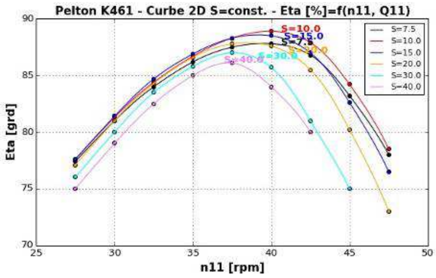


Figure 29. $\eta = f(n_{11})$ 2D Curves for S parameter - K461 Pelton runner

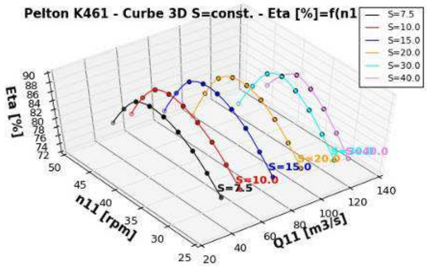


Figure 30. $\eta = f(n_{11}, Q_{11})$ 3D curves for K461 Pelton runner

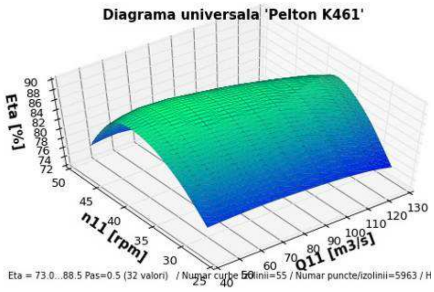


Figure 31. $\eta = f(n_{11}, Q_{11})$ 3d surface for K461 Pelton runner

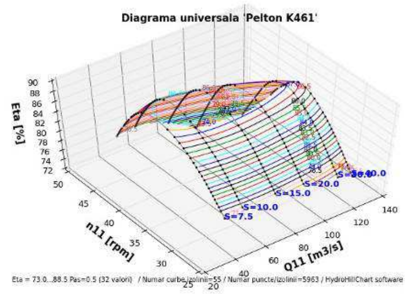


Figure 32. The 3D intersection curves with constant efficiency-K461 Pelton runner

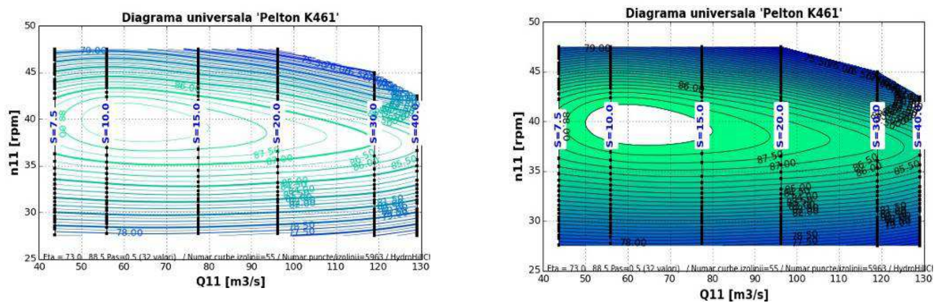


Figure 33. The hill chart for K461 Pelton runner

4. Conclusions

The paper presents the universal characteristics of two models of Pelton runners, which are determined by using the **HydroHillChart** - **Pelton module** software. This complex application enables, besides the viewing of the tested runner hill chart, the independent viewing of the interpolation curves $\eta = f(n_{11})$ for each injector needle opening, a diagram containing the interpolation curves for all of the injector needle openings, the envelope curve of maximum efficiency, curves $\eta = f(S)$ and $\eta = f(Q_{11})$ and also the intersection points obtained for a constant value of double unitary speed.

The software helps reduce the time needed to calculate and plot the hill chart diagram for Pelton turbine models and also the time needed to obtain numerical data, that can be exported to an Excel file.

5. Acknowledgments

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