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Empirical Correlations for the Performance of Hydraulic System Handling Water Hyacinth

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Abstract The present study is predicting, by deducing empirical correlations, the effect of varying the operating parameters on the performance of a pumping system handling water hyacinth. Pump suction inclination angle, water height above pump inlet, inlet suction cone diameter, pump flow rate, number of cutter blades, with/without scrapper, plant parts and water hyacinth concentration are the operating parameters. The recovery rate and the effectiveness of pumping system the two most important parameters displayed the performance of the pumping system, are predicted by empirical correlations as function of these operating parameters. Sets of published experimental data in the open literature were used to obtain these empirical correlations. Three different cases are studied. In each case two equations are deduced, one for The recovery rate and the other for the effectiveness of pumping system. These cases covered the pumping system working conditions. The empirical correlations are obtained by using the least squares method (Regression analysis). Comparisons are performed between the results obtained, for The recovery rate and the effectiveness of pumping system, using the deduced empirical correlations and the used experimental data. Finally, general empirical correlations, cover practical operating pumping system ranges, are obtained and show reasonable agreement with the experimental data.

Keywords: *empirical correlations, pumping system, performance, water hyacinth*

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1. Introduction

Water Hyacinth originating from the Amazon Basin in South America is a free-floating aquatic weed that is found worldwide. Water Hyacinth is considered the world’s worst aquatic weed [1]. It causes global annual losses in excess of US$ 100 million for hydro-electricity plants, irrigation schemes, fisheries, riparian communities and activities relying on water transit [2].

Tremendous progress has been made technologically in the last few years in the area of bio-fuel production, fuelled by ever increasing price and shortage of fossil fuel. There are also concerns about global climate change and severe food shortage. Biomass is the least expensive and most globally available resource. Therefore, priority should be shifted towards utilizing biomass, leaving aside food for human consumption. New methodologies of fermentation and hydrolysis of biomass have become available, along with development of transgenic varieties amenable for bio-fuel production. Now is the time to look for new material sources of bio-fuels, which are naturally amenable to processing during extraction of bio-fuel, thus reducing costs drastically and substituting fossil fuels in all aspects. Water hyacinth has long been seen as an invasive species all over the globe and considerable amount of resources have been spent for their control. However, they have certain qualities which can be utilized to produce bio-fuels (both bio-ethanol to power vehicles and motors, biogas to generate electricity) as the plants are low in lignin content and have rapid growth rate. They tend to grow well in water bodies even with low nutrient regime and can be easily mechanically harvested. There are so many alternative uses of these plant species and time has come to look at the plant from a different viewpoint and utilize their potential as much as possible. This tends to generate ample employment particularly in developing world [3].

There have been many discussions regarding substitute materials to replace petroleum and other decreasing natural fuel resources. These can be derived from plants that is, biomass can be converted into hydrocarbons and bio-fuels. It would be of course beneficial to obtain energy from inedible biomass like water hyacinth containing metallic pollutants. Water hyacinth contains large quantity of cellulose that can be converted into bio-ethanol by enzymes. The conversion of biomass into hydrocarbons like methane utilizes a complex but reasonably well understood biochemical route. Digestion of water hyacinth biomass into methane an aerobically under mild conditions of pressure and temperature is possible. Thermal gasification of biomass is possible at much higher temperatures (>500°C) and takes advantage of an equally complex series of chemical reactions that occur between carbon-containing compounds, water and oxygen [4].

By 2025 Egypt as well as Arabic world is expected to suffer from water scarcity. That is why it is a must to manage the existing water on one hand and study other possible strategies to increase water budget on the other. One of the possible solutions is reuse of the sewage water, which could solve part of the water demand and/or compensate for water shortage in the near future. One of the limitations is uncontrolled discharges of wastewater directly to urban systems without adequate treatment. This discharge contains several pollutants, mainly heavy metals. This in turn makes the process of sewage water treatment more expensive and needs extra efforts. One of the recommended methods to overcome this problem is utilizing the plant (phytoremediation) and/or bacteria (bioremediation) for treatment. The aquatic plant water hyacinth is growing abundantly in tropical and subtropical regions of the world [5].

The design of a particular program of water hyacinth control in developing countries is not an easy task. There are socio-economic constraints which may prevent the practice of any particular control method: public opinion led by the journalists of the country who will rightly question all matters regarding the introduction of any bio-agent, chemical compounds, practice of any control measure, the lack of equipment, funding and sufficient personnel trained on control methods to be developed. In addition, there might also be the lack of suitable link between the national institutions involved.

Recently, a few authors investigated usage pumping system for control water hyacinth and studied the method to develop this system to improve its performance. It is important to continue studies to improve water hyacinth mechanical control, but meanwhile there is also a need to design control strategies based on the level of water hyacinth infestations and national socio-economic constraints, but there is a big problem, this problem is, water hyacinth transportation.

Realizing that fresh water hyacinth contains nearly 95% water, most of which has to be extracted before usage, the economic viability of the economic uses must be seriously considered, In any case, utilization must never be considered as an option for controlling the menace of water hyacinth.

To overcome the transportation of water hyacinth problem, the present study used the idea of chopper pumps which used in industrial applications or municipal applications that involve pumping solids-laden slurries. They are a cost-effective means of eliminating pump plugging problems and optimizing performance.

A new system consists of submersible pump with conical inlet device, it's impeller connected with cutter to cutting the water hyacinth to small pieces, occupied a small volume, easy to transported by pages (by this way, one can overcame the water hyacinth transportation by minimized the water hyacinth volume and then one can dump the water hyacinth on the suitable place to avoid any problem-human healthy.

The present study is considered a stage of a research program dealing with the influence of various parameters on the performance of water hyacinth recovery pumping system. Authors studied experimentally the effect of varying the operating parameters on the performance of a recovery pumping system handling water hyacinth. The operating parameters considered in Khalil *et al*. [6] were number of cutter blades, with/without scrapper, plant parts (complete plant, plant without roots and separate leaves) and water hyacinth concentration. Mean while, pump suction inclination angle, water height above pump inlet, inlet suction cone diameter and pump flow rate are the operating parameters considered in Khalil *et al*. [7]. Also, Khalil *et al.* [8] studied the influence of the centrifugal pump impeller type on the performance of the recovery pumping system. Moreover, Khalil *et al*. [9] introduced a parameter called the effectiveness to evaluate the performance of a recovery pumping system handling water hyacinth. The effectiveness is defined as the ratio between the rate of water hyacinth quantity collected and the mixture flow rate (water-water hyacinth). In addition, Khalil *et al*. [10] deals with the effect of varying cutter blade number, β and cutter speed, N, to determine changes in recovery water hyacinth volume.

Also, Khalil *et al.* [11] studied the effect of the pump intake suction cone length ratio, L_C/R_i and the effect of using grinder on the performance of water hyacinth recovery pumping system.

The water hyacinth recovery rate, NRR and The effectiveness of the pumping system, E, are the main paremeters of the performance of the pumping system and one can be defined from Equations 1 and 2

The water hyacinth recovery rate, NRR is calculated as follows:

$$NRR=M/T \tag{1}$$

Where:

M = water hyacinth recovery mass

T = time of collecting water hyacinth recovery mass.

The effectiveness of the pumping system, E, is defined as:

$$E=K.M_C/[\rho_{wh}.\ Q] \tag{2}$$

Where:

K = Constant

M_c = the rate of water hyacinth quantity collected

ρ_{wh} = water hyacinth density

Q = the mixture flow-rate

Based on the experimental tests and detailed uncertainty analysis, the measurements were estimated to be accurate to within 2% for water hyacinth recovery rate, NRR, 3% for pumping system effectiveness, E.

The present study attempts to fill the gap between the theoretical and experimental results of the recovery pumping system. It is a step further towards making the things easier by putting the outcomes from the experiments, performed in the previously mentioned stages, into suitable as well as useable empirical formulas. These formulas, after validation, can be used directly, with confidence, to obtain the performance of pumping system working in real operating conditions. Therefore, the experimental data obtained in the previous stages, Khalil *et al*. [6-11], will be used in the present study to obtain the empirical correlations. The objectives of the present study is predict a general empirical correlations for water hyacinth recovery rate and the effectiveness of recovery pumping system, using the obtained experimental data, as function of the operating parameters.

2. Materials and Methods

2.1. Specifications of the Used Data

A schematic diagram and photo of the recovery pumping system used in the present study is shown in (Figure. 1, Figure 2, Figure 3). It is important to specify the data, first, in order to determine the validity ranges in which these correlations can work effectively. The experimental data covered the following ranges:

- The inclination angle of the centerline of the pump suction cone with respect to the vertical plane , θ, from 5 to 25
- Water height above pump inlet, H, from 25mm to 125mm
- Inlet suction cone diameter, D_i ,($D_i = 2 R_i$) from 10mm to 45mm
- Pump flow rate, Q, from 0 to 22.5m^3/ h
- Water hyacinth concentration, M, from 0.5kg to 2kg
- Inlet cone length, L_C, from 75mm to 225mm
- Cutter speed, N, from 1900 rpm to 2900 rpm
- The cutter blade number, β, from 2 to 5

More details regarding the used experimental data can be found in Azouz [12] and Azouz et al. [13].

The experimental results of Khalil *et al*. [6-11] that used in the present study are obtained for three different types of centrifugal pump impellers. These types are:

- Semi-open impeller
- Vortex impeller
- Double channel impeller

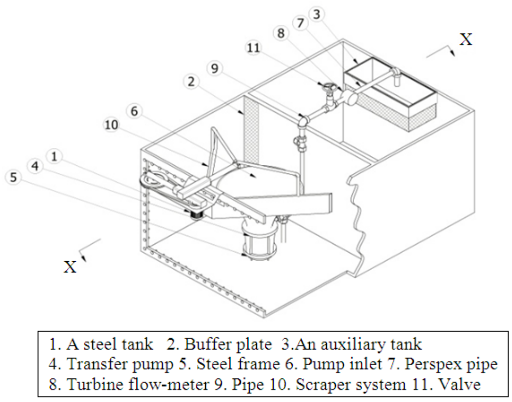

Figure 1. Schematic diagram of experimental setup

Figure 2. The water hyacinth in the experimental tank

Figure 3. Photographs illustrate the processes of the collection and separation of the recovered Nile water hyacinth in the auxiliary tank

2.2. The Empirical Correlations

The experimental data used to obtain the empirical correlations, show that the water hyacinth recovery rate, NRR, increases with the increase of pump suction cone inlet diameter, D_i and water- water hyacinth mixture flow rate, Q and water hyacinth concentration, M. It decreases with the increases of the inclination angle of the centerline of the pump suction cone with respect to the vertical plane, θ. The effect of varying water- water hyacinth mixture height above the pump suction cone inlet (submergence height), H , inlet cone length, L_c and cutter speed, N, on the water hyacinth recovery rate depends on the range of these values. Meanwhile, the effectiveness of water hyacinth recovery pumping system increases with the increase of pump suction cone inlet diameter, D_i and It decreases with the increases of the inclination angle of the centerline of the pump suction cone with respect to the vertical plane, θ. The effect of varying water- water hyacinth mixture height above the pump suction cone inlet (submergence height), H, water-water hyacinth mixture flow rate ,Q, the water hyacinth concentration, M, inlet cone length, L_c and cutter speed, N, on the effectiveness of water hyacinth recovery pumping system depends on the range of this parameters.

To find the empirical correlations for water hyacinth recovery rate, NRR and pumping system effectiveness, E, the procedure will be as follows:

The empirical formula for the water hyacinth recovery rate, NRR is assumed in the form of power function for the operating conditions, (Equation. 3), taking into consideration the pervious parameters. These parameters are pump suction cone inlet diameter, D_i, water- water hyacinth mixture flow rate, Q, water hyacinth concentration, M, the inclination angle of the centerline of the pump suction cone with respect to the vertical plane, θ, water-Nile water hyacinth mixture height above the pump suction cone inlet (submergence height), H, inlet cone length, L_c , cutter speed, N and cutter blade number:

$$NRR = A_1 \left(\frac{M}{M_{max}}\right)^{b1} \left(\frac{Q}{Q_{max}}\right)^{c1} \left(\frac{D_i}{D_o}\right)^{e1} \left(\frac{H_i}{D_o}\right)^{f1} \left(1+\cos\theta\right)^{j1} \left(\frac{L_c}{R_i}\right)^{k1} \left(\frac{N}{N_{max}}\right)^{o1} \left(\frac{\beta}{\beta_{max}}\right)^{h1} \quad (3)$$

Similarly, pumping system effectiveness, E, (Equation 4), is assumed as:

$$E = A_2\left(\frac{M}{M_{max}}\right)^{b2}\left(\frac{Q}{Q_{max}}\right)^{c2}\left(\frac{D_i}{D_o}\right)^{e2}\left(\frac{H_i}{D_o}\right)^{f2}\left(1+\cos\theta\right)^{j2}\left(\frac{L_c}{R_i}\right)^{k2}\left(\frac{N}{N_{max}}\right)^{o2}\left(\frac{\beta}{\beta_{max}}\right)^{h2} \quad (4)$$

Equations 3, 4 are transformed to the form of a linear function by taking the (ln) function to each side. Applying the regression to the above equation (using the least squares method), the constants A, b, c, e, f, j, k,o and h are obtained, Table1. Show the empirical correlations and their constants and constrains for various type of impeller.

3. Results and Discussion

Figure 4 shows the variation of the calculated water hyacinth recovery rate, NRR, with the corresponding measurements for semi open impeller under various operating conditions. The straight line shown in Figure 4 and the other coming figures (Figures 4-9), represents the equality of the calculated and the measured NRR, E results. Consequently, the scatter of the presented points around this line is an indication of the deviation between the two sets of NRR or E results. The average difference between the calculated and the measured NRR results presented in Figure 4 is 19.3%.

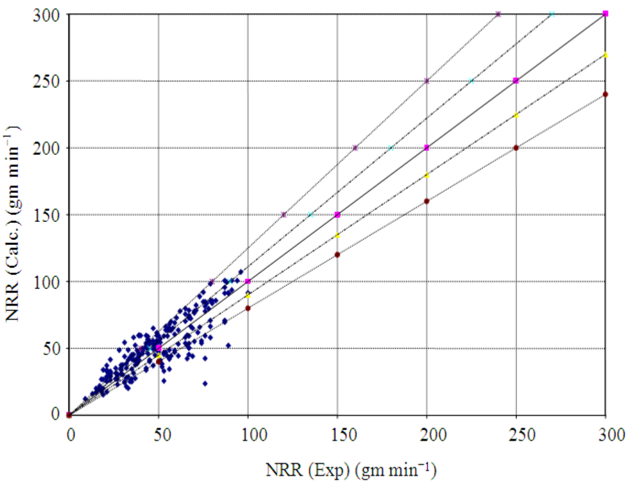

Figure 4. comparisons between the calculated and the measured water hyacinth recovery rate, NRR, for semi-open impeller

Figure 5 shows the variation of the calculated water hyacinth recovery rate, NRR, using the obtained correlation, with the corresponding measurements for vortex impeller under various operating conditions. The average difference between the calculated and the measured NRR results is 13.1%.

Figure 6 shows the variation of the calculated water hyacinth recovery rate, NRR, with the corresponding measurements for double channel impeller. The average difference between the calculated and the measured NRR results is 12.2%.

Figure 7 shows a comparison between the calculated pumping system effectiveness, E, with the corresponding measurements for semi open impeller under various operating conditions. The average difference between the calculated and the measured E results is 15.7%.

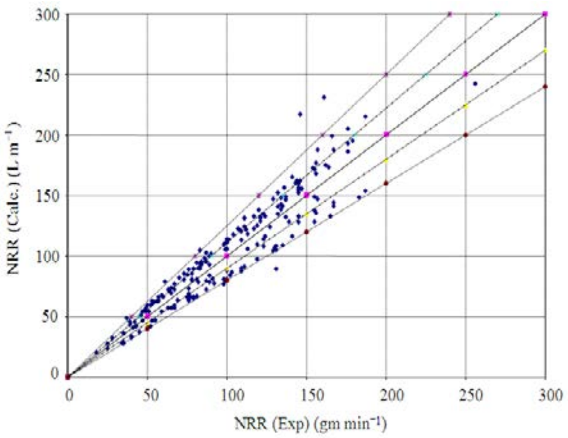

Figure 5. comparisons between the calculated and the measured water hyacinth recovery rate, NRR, for vortex impeller

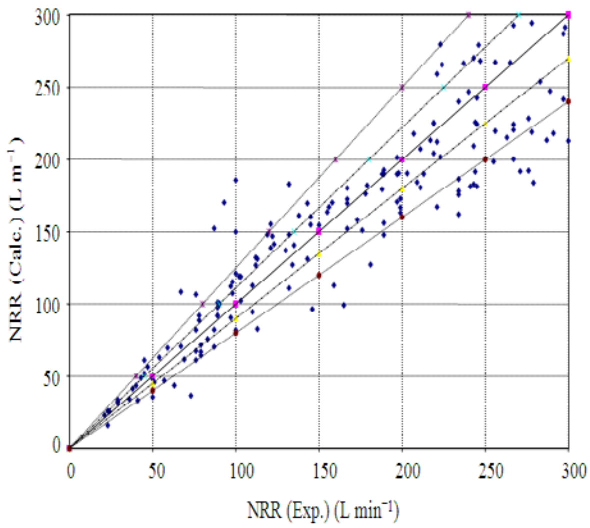

Figure 6. Comparisons between the calculated and the measured water hyacinth recovery rate, NRR, for double channel impeller

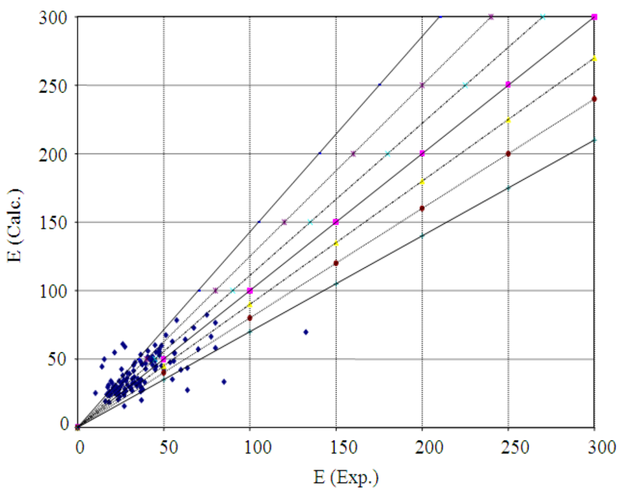

Figure 7. Comparisons between the calculated and the measured recovery pumping system effectiveness, E, for semi-open impeller

Table1. The empirical correlations and their constants and constrains

E	Correlation	Constant	Constrains
5	$NRR = A_1\left(\frac{M}{M_{max}}\right)^{b1}\left(\frac{Q}{Q_{max}}\right)^{c1}\left(\frac{D_i}{D_o}\right)^{e1}\left(\frac{H_i}{D_o}\right)^{f1}(1+Cos\theta)^{j1}\left(\frac{L_c}{R_i}\right)^{k1}\left(\frac{N}{N_{max}}\right)^{o1}\left(\frac{\beta}{\beta_{max}}\right)^{h1}$	A1= 39.0210675 b1 = -0.12741972 c1 = 0.29169415 e1 = 0.53536717 f1 = 0.22595572 j1 = -0.03427679 k1= 0.15836813 o1= 2.30380446 h1= 0.72863581	Semi-open impeller
6	$NRR = A_1\left(\frac{M}{M_{max}}\right)^{b1}\left(\frac{Q}{Q_{max}}\right)^{c1}\left(\frac{D_i}{D_o}\right)^{e1}\left(\frac{H_i}{D_o}\right)^{f1}(1+Cos\theta)^{j1}\left(\frac{L_c}{R_i}\right)^{k1}\left(\frac{N}{N_{max}}\right)^{o1}\left(\frac{\beta}{\beta_{max}}\right)^{h1}$	A1= 77.96110108 b1 = 0.316463027 c1 = 0. 8266337 e1 = 1.16046454 f1 = 0.19921517 j1 = 0.130031558 k1= 0.634492595 o1= 3.28762528 h1= 1.02123002	Vortex impeller
7	$NRR = A_1\left(\frac{M}{M_{max}}\right)^{b1}\left(\frac{Q}{Q_{max}}\right)^{c1}\left(\frac{D_i}{D_o}\right)^{e1}\left(\frac{H_i}{D_o}\right)^{f1}(1+Cos\theta)^{j1}\left(\frac{L_c}{R_i}\right)^{k1}\left(\frac{N}{N_{max}}\right)^{o1}\left(\frac{\beta}{\beta_{max}}\right)^{h1}$	A1= 138.8958285 b1 = 0.179497713 c1 = 0.0.81209627 e1 = 1.03396209 f1 = 0.06707989 j1 = 0.098639462 k1= 0. 52477678 o1= 3.3291781 h1= 0.87245745	Double channel impeller
8	$E = A_2\left(\frac{M}{M_{max}}\right)^{b2}\left(\frac{Q}{Q_{max}}\right)^{c2}\left(\frac{D_i}{D_o}\right)^{e2}\left(\frac{H_i}{D_o}\right)^{f2}(1+Cos\theta)^{j2}\left(\frac{L_c}{R_i}\right)^{k2}\left(\frac{N}{N_{max}}\right)^{o2}\left(\frac{\beta}{\beta_{max}}\right)^{h2}$	A2= 15.26537576 b2 = -0.08868699 c2 = -0.65408139 e2 = 0.639462 f2 = 0.2719402 j2 = -0.07957214 k2= 0.20842305 o2= 5.85909926 h1= 0.19919774	Semi-open impeller
9	$E = A_2\left(\frac{M}{M_{max}}\right)^{b2}\left(\frac{Q}{Q_{max}}\right)^{c2}\left(\frac{D_i}{D_o}\right)^{e2}\left(\frac{H_i}{D_o}\right)^{f2}(1+Cos\theta)^{j2}\left(\frac{L_c}{R_i}\right)^{k2}\left(\frac{N}{N_{max}}\right)^{o2}\left(\frac{\beta}{\beta_{max}}\right)^{h2}$	A2= 99.3853823 b2 = 0.39711431 c2 = 0.12907585 e2 = 0.50871223 f2 = 0.31640199 j2 = 0.045709306 k2= 0.08554508 o2= 8.70763553 h1= -0.04303112	Vortex impeller
10	$E = A_2\left(\frac{M}{M_{max}}\right)^{b2}\left(\frac{Q}{Q_{max}}\right)^{c2}\left(\frac{D_i}{D_o}\right)^{e2}\left(\frac{H_i}{D_o}\right)^{f2}(1+Cos\theta)^{j2}\left(\frac{L_c}{R_i}\right)^{k2}\left(\frac{N}{N_{max}}\right)^{o2}\left(\frac{\beta}{\beta_{max}}\right)^{h2}$	A2= 6.908545773 b2 = 0.273758539 c2 = 0.04359237 e2 = 2.13294147 f2 = 0.18175422 j2 =0.029562726 k2= 1.74977548 o2= 9.76101193 h1= -0.42912323	Double channel impeller

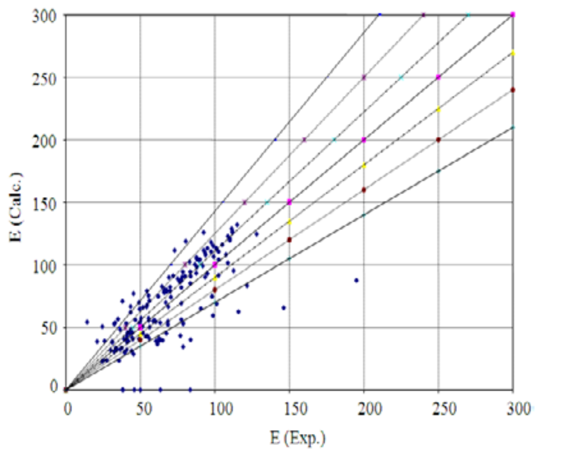

Figure 8. Comparisons between the calculated and the measured recovery pumping system effectiveness, E, for vortex impeller

Figure 8 shows a comparison between the calculated pumping system effectiveness, E, with the corresponding measurements for vortex impeller under various operating conditions. The average difference between the calculated and the measured E results is 15.8%.

Figure 9 shows a comparison between the calculated pumping system effectiveness, E, with the corresponding measurements for double channel impeller under various operating conditions. The average difference between the calculated and the measured E results is 17.3%.

It is important to note that although there is a notice difference between the values of the correlations constants for the three impeller types, (this is a direct reflect of the used experimental date of Khalil *et al*. [8] the average difference between the calculated and experimental results for all of them is within a narrow range, Table 2.

In addition, the magnitude of the average difference between the calculated results and the corresponding experimental results is, in general, function of the number of parameters used. This may shed some light on the results of the present study due to the inclusion of many parameters in the study.

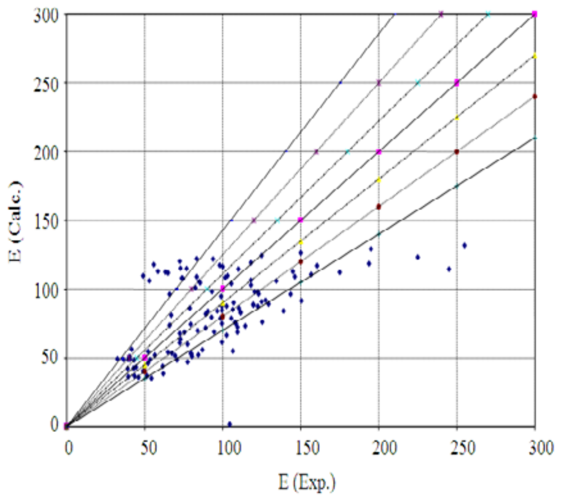

Figure 9. Comparisons between the calculated and the measured recovery pumping system effectiveness, E, for double channel impeller

Table 2. Average difference between the calculated and experimental results for different impeller type

#	Impeller type	$\Delta NRR_{average}$ (%)	$\Delta E_{average}$ (%)
1	Semi-open	19.3	15.7
2	Vortex	13.1	15.8
3	Double channel	12.2	17.3

Therefore, some researchers prefer to minimize the number of parameters in order to obtain a narrow range of accuracy for their empirical correlations. In the present study the generality was preferred over the accuracy by using the experimental data that include all the parameters measured by Khalil *et al*. [6-11].

The average difference between calculated, NRR_{calc} and measured, NRR_{Exp}, water hyacinth recovery rate, NRR, results is obtained as follows in (Equation 11):

$$NRR = \frac{\sum_{n=1}^{n=N} \left| \frac{NRR_{Calc} - NRR_{Exp}}{NRR_{Exp}} \times 100 \right|}{N} \quad (11)$$

Similarly, The average difference between calculated, E_{calc} and measured, E_{Exp}, water hyacinth pumping system effectiveness, E, results is obtained as follows in (Equation 12):

$$E = \frac{\sum_{n=1}^{n=N} \left| \frac{E_{Calc} - E_{Exp}}{E_{Exp}} \times 100 \right|}{N} \quad (12)$$

where, N is the total number of data.

4. Conclusion

- The present study is concerned with developing empirical correlations to estimate the water hyacinth recovery rate, NRR and effectiveness, E, as a function of operating parameters
- The present study can be regarded as a study putting experimentally measured parameters on an empirical footing. Practically, this may make it easier for the designer of pumping system to take into consideration these effective parameters
- General empirical correlations, cover practical operating pumping system ranges, are obtained and show reasonable agreement with the experimental data

Finally, it is important to re-emphasize here that the empirical correlations, although valid for the test data used, are not necessarily applicable over the wide range of possible operating conditions. Therefore, the present proposed empirical correlations can be regarded as a step towards reducing the difference between experimental and theoretical results in the area of water hyacinth recovery pumping system.

References

[1] Lata, N. and V. Dubey, "Eichhornia crassipes a suitable economic feed" The world's worst aquatic weed. J. Food Technol., 8. 102-105. 2010.

[2] Adebayo, R.A. and U.O. Uyi, "Biological control of invasive weed species" Nigerian experience. Int. J. Agric. Res., 5. 1100-1106. 2010.

[3] Bhattacharya, A. and P. Kumar, "Water hyacinth as a potential biofuel crop" Electronic J. Environ., Agric. Food Chem., 9. 112-122. 2010.

[4] Ohno, H. and Y. Fukaya, "Task Specific Ionic Liquids for Cellulose Technology" Chem. Lett., 38. 2-6. 2009.

[5] Medhat, I. and A. Zarrag, "Mechanism of Pollution Control for Aquatic Plant Water Hyacinth". Open Spectroscopy J., 4. 10-15. 2010.

[6] Khalil, M.F., S.Z. Kassab, A.A.A. Naby and A. Azouz, "Parametric performance study of a recovery pumping system handling Nile water hyacinth". Eur. J. Sci. Res., 38. 81-95. 2009.

[7] Khalil, M.F., S.Z. Kassab, A.A.A. Naby and A. Azouz, "Performance of a pumping system handling Nile water hyacinth under variable operating conditions" J. Int. Environ. Application Sci., 5. 99-112. 2010a.

[8] Khalil, M.F., S.Z. Kassab, A.A.A. Naby and A. Azouz, "Influence of pump impeller type on the performance of a recovery pumping system handling Nile water hyacinth" Eur. J. Sci. Res., 41. 497-514. 2010b.

[9] Khalil, M.F., S.Z. Kassab, A.A.A. Naby and A. Azouz, "Effectiveness of a recovery pumping system handling Nile water hyacinth". Am. J. Sci. Ind. Rec., 1. 56-65. 2010c.

[10] Khalil, M.F., S.Z. Kassab, A.A.A. Naby and A. Azouz, "Recovery pumping system handling water hyacinth: Volume reduction criteria" Am. J. Sci. Ind. Rec., 1. 618-627. 2010d.

[11] Khalil, M.F., S.Z. Kassab, A.A.A. Naby and A. Azouz, "Effect of varying the inlet cone length and using grinder on the performance of a recovery pumping system handling water hyacinth" Canadian J. Mechanical Sci. Eng., 2. 147-156. 2011.

[12] Azouz, A., Performance of a pumping system handling Nile water hyacinth under variable operating conditions. PhD thesis, faculty of enginerring, Alexandria University, Egypt. 2012.

[13] Azouz, A., Khalil, M.F., Kassab, S.Z. and Abdel Naby A.A., Performance of a pumping system handling Nile water hyacinth. LAP LAMBERT, Academic Publishing, Deutschland, Germany. 2012.