A teaching methodology based on Mathcad for improving the calculation of pumping power

Antonio Abad Cuadri [1,*], José Enrique Martín-Alfonso[1], Juan Urbano[2]

[1]*Departamento de Ingeniería Química, Centro de Investigación en Tecnología de Productos y Procesos Químicos (Pro²TecS), Campus de 'El Carmen', Universidad de Huelva, 21071, Huelva (Spain).*

[2]*Departamento de Química, Facultad de Ciencias Experimentales, Campus de El Carmen, Universidad de Huelva, Huelva (Spain).*

* Author to whom correspondence should be addressed:

A.A. Cuadri

E-mail: antonio.cuadri@diq.uhu.es

Phone: +34 959 21 98 82

Fax: +34 959 21 93 85

ABSTRACT

Some of the most important engineering skills required nowadays are related with the management of computational tools. This study proposes the implementation of a novel teaching methodology for improving the calculation of pumping power by using the Mathcad software. This methodology includes: (1) training courses on initiation to Mathcad, (2) the delivery of a report with theoretical considerations about pumping power, the problem statement, the traditional procedure to solve it, as well as the main indications to do it with Mathcad, and (3) a virtual platform conceived as a meeting space. The assessment of this educational experience, which was carried out with the second-year chemical engineering students enrolled in the Fluid Flow course, revealed that Mathcad is a powerful computational tool for them. Thus, it eliminates the mathematical difficulties, facilitates the understanding of the phenomenon under consideration and the study that the input variables exert on the solution, and also increases the motivation of the students for solving other engineering problems. Therefore, these results support the hypothesis that computational tools like Mathcad direct chemical engineering students towards successful learning.

Keywords: pumping power, fluid flow, computational tools, Mathcad, educational experience

1. INTRODUCTION

Higher university education in the 21st century requires students to master a broad set of competences that make them suitable for their effective inclusion in the current knowledge society. Among all these competences, the management of new information and communication technologies (ICTs) is noteworthy (Barak, 2018; Juuso, 2018). These ICTs can materialize in the ability to use digital technologies, computers, communication tools, as well as devices and applications to access, manage, create and communicate information to meet individual or social objectives (NRC, 2012; OECD, 2015). The development of the personal computer in the early nineteen-eighties, and the appearance of commercial Internet providers a few years later, brings significant changes in chemical engineering problem-solving. As a consequence of these changes, the numerical calculations are based nowadays on mathematical software packages and simulators. Some illustrative examples are described below: a) XSEOS is an Excel add-in for computer properties with thermodynamic model often used for teaching chemical engineering thermodynamics (Castier and Amer, 2011); b) Matlab is used for educating students in chemical process control (Li and Huang, 2017); c) Polymath can be employed for both chemical equilibrium calculations (Shacham and Brauner, 2015) and chemical reaction engineering (e.g., modelling isomerization of unsaturated fatty acid with catalyst deactivation) (Mahecha-Botero et al., 2011); d) EMSO simulator is a powerful tool for process modeling, dynamic simulation and optimization of chemical processes (Ospino et al., 2017); e) Aspen Plus is used for a better understanding of separation processes (e.g., distillation) (Calvo and Prieto, 2016); f) IPython software has been applied for educating kinetics of complex heterogeneously-catalyzed reactions (Golman, 2016); g) Mathematica software can be applied to transient chemical engineering processes (Mejri et al., 2018). Although it is well known that in the professional life the engineer has at his disposal the use of different softwares for the resolution, control and simulation of engineering systems, their implementation at the university level is only reduced for specific courses designed to meet these objectives. Usually, these courses are insufficient to acquire the best knowledge about the software, leaving the interest of students to complete their training. Therefore, it is very important for chemical engineering students to learn and practice the use of these computational tools (Shacham and Brauner, 2015). In this paper, the calculation of pumping power to transport a petroleum fraction between two tanks by using a centrifugal pump, and the knowledge of its characteristic curves, is carried out by the usage of Mathcad. This software combines some of the best features of spreadsheets and symbolic math programs. It provides a good graphical user interface and can be used to efficiently manipulate large data arrays, to perform symbolic calculations, and to easily construct graphics (Abbas and Al-Bastaki, 2002). Therefore, the main advantage of using this software to teach chemical engineering students to solve engineering problems lies in the fact that they focus on the fundamental concepts rather than on the mathematical solution.

All the considerations above in mind, here it is proposed the fact that second-year chemical engineering students enrolled in the course of Fluid Flow acquire new skills about computational tools through the use of Mathcad, thus enabling them to solve more quickly and efficiently a common engineering problem like the calculation of pumping power. In addition, with the development of this education experience, other objectives are proposed:

- To create a high level of awareness in the students about the real use of computer programs that facilitate the resolution of problems.
- To reduce the time of mathematical resolution that addressing engineering problems

entails.

- To create an entrepreneurial spirit in the students which allows them to make their own Mathcad files, using their code, and thus approach the different problems that may arise during their working and professional life in a more efficient and autonomous way.

The teaching methodology consisted of two steps: i) firstly, students received training courses on initiation to Mathcad, where they could learn the basic notions about this software, and ii) secondly, students solved an exercise about pumping power by using Mathcad. With the idea of quantifying the satisfaction degree of the students with the teaching methodology, as well as with the use of Mathcad, students answered specific questions on these matters. They valued the use of this software as a computational tool reporting many advantages for solving engineering problems (like the calculation of pumping power), since it allows them to get a precise solution eliminating time of mathematical resolution, with a better understanding of the theoretical foundation for the proposed phenomenon and, consequently, motivating students to continue implementing it.

2. THEORETICAL CONSIDERATIONS

As will be described in the "Teaching methodology" section, in order to help students solve the exercise with Mathcad, they will be provided with the underlying theory of pumping power calculations. It might be summarized in the following points:

2.1. The energy conservation equation

When an incompressible fluid is transported by a cylindrical pipe, the balance of the total energy per unit of mass applied between the extremes of the system ("1" initial and "2" final points, respectively) is:

$$\begin{pmatrix}\text{Rate of}\\ \text{kinetic energy}\end{pmatrix}+\begin{pmatrix}\text{Rate of}\\ \text{potential energy}\end{pmatrix}+\begin{pmatrix}\text{Rate of}\\ \text{pressure energy}\end{pmatrix}+\begin{pmatrix}\text{Energy loss}\\ \text{due to friction}\end{pmatrix}=\left(\text{Required energy}\right) \quad (1)$$

Eq. (1) can also be written as:

$$\left(\frac{V_2^2}{2\alpha_2}-\frac{V_1^2}{2\alpha_1}\right)+g(z_2-z_1)+\frac{P_2-P_1}{\rho}+\sum F=W \quad (2)$$

where V is the velocity, α is a factor that takes the value of 0.5 or 1 for laminar or turbulent regime, g is the gravitational constant, z is the height with respect to a reference system, P is the pressure and ρ is the density. If Eq. (2) is divided per g, this results in the energy equation conservation expressed in the head form:

$$\left(\frac{V_2^2}{2g\alpha_2}-\frac{V_1^2}{2g\alpha_1}\right)+(z_2-z_1)+\frac{P_2-P_1}{\rho g}+\frac{\sum F}{g}=H \quad (3)$$

In the case of internal flow of a fluid through a pipe, the friction energy losses due to the friction, ∑F, is calculated by dividing Fanning equation per the fluid density, and it can be expressed as follows:

$$\sum F=\frac{2fLV^2}{D} \quad (4)$$

where L and D are the length and diameter of the pipe, respectively, and f is the friction factor. The last one can be calculated from the Chen equation:

$$\frac{1}{\sqrt{f}}=-4\log\left[\frac{1}{3.7065}\left(\frac{\varepsilon}{D}\right)-\frac{5.0452}{\mathrm{Re}}\log\left[\frac{1}{2.8257}\left(\frac{\varepsilon}{D}\right)^{1.1098}+\frac{5.8506}{\mathrm{Re}^{0.8981}}\right]\right] \quad (5)$$

where ε is the roughness and Reynolds number, Re, is:

$$\mathrm{Re}=\frac{\rho VD}{\mu} \quad (6)$$

being μ the viscosity of the fluid.

2.2. Pumping power calculation

Power is consumed by a pump in order to move and increase the pressure of a fluid. The power requirement of the pump depends on a number of factors including the pump and motor efficiency, fluid's properties and flow rate, making necessary to define some concepts:

- Theoretical power pump (P_t): it is calculated by multiplying the energy required from Eq. (2), W, and the mass flow rate that goes through the pump, $\dot{m}$.

$$P_t = W\dot{m} \quad (7)$$

- Hydraulic efficiency (η_h): it is defined as the fraction of energy applied by the pump on the fluid, which is actually invested to increase its energy, and it is calculated as:

$$\eta_h = \frac{W - \sum F_i}{W} \quad (8)$$

  where $\sum F_i$ is the energy loss due to the internal mechanical elements of the pump. Thus, this parameter takes into account the internal energy loss of the pump.

- Motor efficiency (η_m): it is the theoretical power pump (P_t) divided per the drive power (P_d) (i.e., the power for moving its internal mechanical elements):

$$\eta_m = \frac{P_t}{P_d} \quad (9)$$

- Total efficiency (η_t): it is calculated from both hydraulic and motor efficiency:

$$\eta_t = \eta_h \eta_m = \frac{W - \sum F_i}{W}\frac{P_t}{P_d} = \frac{W - \sum F_i}{W}\frac{W\dot{m}}{P_d} = \frac{\left(W - \sum F_i\right)Q\rho}{P_d} \quad (10)$$

2.3. Pump characteristic curves

The performance of a centrifugal pump can be shown graphically by plotting the course of the following parameters against volumetric flow rate (Q): head (H), drive power (P_d) and total efficiency (η_t). These curves allow us to know the conditions for the best performance of centrifugal pumps and, therefore, are really useful.

3. PROBLEM STATEMENT

It is desired to transport a petroleum fraction through a pipe of 20 cm of internal diameter and 2 km in long, from a reaction tank at 110 kN/m^2 (Tank A) to a storage tank at 125 kN/m^2 (Tank B) whose level is 15 m above that corresponding to the reaction tank. The centrifugal pump is located at the outlet of the Tank A, 10 m below the liquid level in it and assuming friction losses inside the pump of 20 J/kg. Calculate the drive power of the pump.

<u>Data:</u>

Density: 705 kg/m^3 ; Viscosity: $15\cdot 10^{-3}$ Pa·s ; Roughness: 0.4 mm.

The characteristic curves, valid for volumetric flow rate up to 0.1 m^3/s, are:

$H=122-115Q-5560Q^2$ (11)

$\eta_t=33+2376Q-34614Q^2$ (12)

Units: H [m] ; Q [m^3/s] ; η_t [%].

4. PROBLEM SOLUTION BY USING MATHCAD

As for other engineering questions, the first step will be to evaluate the available data supplied by the problem statement as well as the equations that are applicable. For the resolution of this case, since the characteristic curve of head (H) vs. volumetric flow rate (Q) is provided, it is proposed to apply the energy equation conservation expressed in the head form (Eq. 3) between the levels of both tanks (i.e., point “1” and point “2” will be hereinafter referred to as the level of Tank A and B, respectively). Thus, considering that the diameter of both tanks is much larger than the diameter of the pipe, it is likely to assume that $V_1 \approx V_2 \approx 0$. If the attention is now focused on the drive power (P_d), it would be easily calculable if Q or V are known, since Q and V are related by the flow area. In this sense, with the value of Q, W and η_t would be calculated from Eqs. (3) and (12), respectively, and the value of P_d from Eq (10). Consequently, the greatest challenge is to determine the volumetric flow rate (Q).

The traditional procedure used in the Fluid Flow course for solving this problem was to manually draw the operation line of the pump (which is obtained from the energy equation conservation, Eq. (3)) and the characteristic curve of H vs. Q (Eq. (11)), being the intersection of both lines the desired value of Q; however, the inaccuracy and the high time required by this "manual" procedure can be eliminated by using Mathcad. To that end, firstly, all known variable values are entered at the beginning of the spreadsheet (Figure 1): height, pressure, density, viscosity, length and diameter of the pipe, roughness and friction losses inside the pump. Following this, the objective is now to create a function that gives us the points of the operation line from Q values, which in turn requires velocity (V), Reynolds number (Re) and friction factor (f) as a function of Q. Thus, as the characteristic curves are valid for Q values up to 0.1 m^3/s, a data list with values equally distributed between 0.01 and 0.1 m^3/s is defined, and their corresponding V, Re, f(Q) values and points of the operation line (named as "Hoperation_line(Q)") are automatically calculated from the previous equations. All these considerations should be gathered in the next section of our spreadsheet and are illustrated in Figure 2 (some comments have been also included in bold type). Once the data corresponding to the operation line is available, it is necessary to compile them, and also Q values, in two matrices, before being drawn (Figure 3).

As commented previously, the volumetric flow rate passing through the pump (which will be then referred to as "Q_solution" in the spreadsheet) is the intersection point between the operation line and the H vs. Q characteristic curve. Here, the points of the operation line are fitted by using a cubic spline interpolation function available in Mathcad. This interpolation function connects two consecutive points by a third degree polynomial, so that the polynomial by sections has continuous first and second derivatives for each value of the independent variable. As can be observed in Figure 4, firstly, the *cspline* function is used to create a cubic spline vector (v) with the independent and dependent data (i.e., the values of Q and points of the operation line, respectively), which have been previously defined in two vectors (see Figure 2). Then, f(x) is defined with the *interp* function which allows us to get the interpolated values; it contains the cubic spline vector (v), Q and points of the operation line ("Hoperation_line(Q)") vectors, and the real value of the independent variable in which the interpolation curve is evaluated (x). As can be observed, f(x) is well-fitted to the points of the operation line, but, to be more realistic, f(x) should be considered in the same range of Q (see Graph B in Figure 4). In order to add the H vs. Q characteristic curve to the above graph, it has been included in the spreadsheet (with its corresponding units) and the result is shown in Figure 5.

The Q value passing through the pump (Q_solution) is achieved by solving the system of equations formed by the H vs. Q characteristic curve and f(x), as can be illustrated in Figure 6. For this purpose, it is necessary to include three sections: a) in the first, all known values should be entered (they have been already included in the beginning of the spreadsheet, Figure 1), b) in the second, Mathcad requires a guess value of the unknown variables (in this case, Q) and, c) in the third section, the system of equations and the functions *Given* and *Find* are implemented. The volumetric flow rate (0.067 m^3/s) and its corresponding head value of 89.065 m, which can be checked from both characteristic curve and f(x) function, are the correct solution (see Graph in Figure 6). Next, a total efficiency of 0.361 is obtained from the η vs. Q characteristic curve, Eq.(12), and, finally, a drive power of $1.122 \cdot 10^5$ W is obtained from the Eq.(10).

5. USING THIS EXERCISE IN THE CLASSROOM

5.1. Students

The actual task of solving the calculation of the pumping power for a centrifugal pump was carried out by second-year chemical engineering students (36 people in total), under the scope of the course named Fluid Flow (reference: 606210204), tutored by the corresponding author of this paper. This course was intended to provide students with the necessary knowledge about the basic principles of fluid mechanics and its application to solve problems in the field of engineering, calculation of pipes, channels and fluid systems. Going back to the students, 10 of them were female and 26 were male, and all of them were aged between 19 and 22 years. The prerequisites of this course included all the usual set of required undergraduate chemical engineering courses (among other, mass and energy balance, thermodynamics or transport phenomena).

5.2. Teaching methodology

In order to achieve the aforementioned objectives in the Introduction section, the aim is to design an adequate teaching methodology so that students can get the most out of Mathcad. The teaching methodology consists of two tasks:

<u>Task 1. Training courses on initiation to Mathcad</u>

Two 5 hour seminars dealing with the basic notions about Mathcad and aimed to at our students were held near the end of the academic semester and immediately after the lectures focusing on the use of centrifugal pump and its characteristic curves. These initiation courses took place in the computer rooms at the University of Huelva itself, where a version of Mathcad Prime 4.0 is available, and dealt with:

- Session 1: a) Description of the software-user interface, b) definition of simple functions and c) 2D graphical representation.
- Session 2: a) Resolution of system of linear equations, b) use of spline cubic interpolation function and c) doubts and questions.

All information regarding these training courses to Mathcad were available to students in the Moodle virtual platform of the University of Huelva (http://moodle.uhu.es/). Thus, within this platform, a meeting space between the teacher and the students was created. The date and place of each seminar, support material, tutorial videos, as well as the resolution of the different practical cases made during these seminars could be found in the platform.

Task 2. Calculation of pumping power by using Mathcad

After completing the training courses on initiation to Mathcad, the teacher designed an exercise that enabled students to apply the knowledge acquired to solve specific engineering problems related to Fluid Flow course. In order to do this, the teacher prepared a previous report that was delivered to the students (via Moodle), gathering the following information:

- Theoretical considerations: including all definitions and equations that were useful for the calculation of centrifugal pumping power. It was a format similar to that presented in the "Theoretical considerations" section of the present manuscript.
- Problem statement: it can be equal to the one here proposed in the "Problem statement" section or it is also possible to prepare different exercises changing some initial data such as internal diameter and length of the pipe, distance between tank levels, fluid's properties, characteristic curves, etc. With this, it was sought to emphasize the versatility of the Mathcad spreadsheet for studying the influence of input variables on the final result.
- Traditional procedure to solve the exercise: it enables students to identify the advantages of using Mathcad for solving the calculation of centrifugal pumping power with respect to the traditional procedure, which has been briefly described in the "Problem solution by using Mathcad" section.

- Main indications to solve the exercise through Mathcad: the teacher gives some indications to help students to prepare their Mathcad spreadsheet. It will include the use of Mathcad functions like *cspline*, *interp*, *given* and *find*.

Once the previous report has been prepared and made available to the students on the Moodle platform, they solved the proposed exercise by using Mathcad in a 5h-seminar. The seminar happened right after the two training courses about Mathcad. In addition to the help provided by the previous report, given that there was the possibility of solving the problem through different pathways, students could exchange ideas and proposals among themselves giving rise to a set of possible Mathcad spreadsheets. Thus, the classroom atmosphere that was created promoted the interpersonal relationships and co-operative learning. Finally, students delivered their spreadsheet in Moodle platform, allowing the teacher to create a repository for further evaluation.

5.3. Student feedback and evaluation

In order to quantify the satisfaction degree of the students with the teaching methodology as well as with the use of Mathcad to solve the calculation of pumping power, the students answered specific questions on these matters. With this information, the teacher hoped to detect possible errors and overcome them for future actions. Next, the results obtained by the students enrolled in the Fluid Flow course corresponding to the 2017/2018 academic year were commented.

The first survey was carried out at the end of the second seminar about initiation to Mathcad and, again, it was available in the Moodle platform. The questions and their corresponding responses are displayed in the Figure 7. Students gave positive feedback to the training courses, since 75 or 14 % students considered these training courses with a global evaluation (Q10) of *High* or *Hery High*. Interestingly, although an overwhelming majority of the respondents did not have previous knowledge of Mathcad

(Q1), they do not think it is a complex software, given that only 14 % students marked *Very High* in Q8. As for the teacher, they pointed out that he was committed to this task (Q2), its knowledge about Mathcad was adequate for instructing these courses (Q3) and he knew how to resolve the doubts (Q4). One of the main conclusions that might be drawn from this first survey was that two seminars of 5 hours each were not enough to achieve the required skills to work with Mathcad autonomously, which can be deduced from Q6 and Q7. Supporting even more this assertion, the responses in the opening-ended question move in the same direction and, therefore, it will be a matter to be taken into account for oncoming training courses on initiation to Mathcad. Particularly motivating was the growth of interest in using Mathcad after these courses (Q9), which makes me feel that I have fulfilled one of the main objectives.

The second survey was related to the use of Mathcad for the calculation of pumping power, which was also conducted after students made the proposed exercise, giving rise to the results displayed in Figure 8. The majority of the comments raised by the students (not shown here), also supported by the score obtained in their corresponding questions, make clear that:

- Students preferred to solve the calculation of the pumping power by using Mathcad instead of the traditional procedure (Q1), since the mathematical difficulties are negligible (Q3) and, after making a good template, it is easy to study the effect of the input variables on the final results (Q4).
- The use of Mathcad enables students to understand the theoretical basis behind the pumping phenomenon (Q2), increasing the motivation to use Mathcad for solving other engineering problems that may be presented in the Fluid Flow subject (Q9).

- After completing this exercise with Mathcad, almost half of students were not trained to solve problems raised in other subjects (Q7), which may be due to the fact that the time used for the training courses was too short.

Last but not least, especially rewarding were the talks held with the students during the breaks of the seminars; in a nutshell, they did not come to understand how nowadays these computational tools are not developed at the beginning of any engineering degree.

5.4. Authors' reflections

Based on the conclusions derived from students' surveys, as well as from our own perception, it is clear that the teaching methodology implemented here was really promising, which encourages us to continue applying it. In order to improve future actions, some reflections are presented:

- It would be convenient to give more emphasis to the disadvantage of the traditional methodology (i.e., its inaccuracy and high time required) before students start using Mathcad software. For this purpose, it is proposed to solve the pumping problem by applying the traditional way at the beginning of the seminar about the use of Mathcad.
- Some changes in the survey questions would be advisable. For example, students could score (e.g. on a scale between 1-10) their preference to use Mathcad software instead of the traditional procedure. In addition, students could be asked directly how they believe that the implementation of this teaching methodology could be improved.
- The duration of the training seminars on initiation to Mathcad are clearly insufficient. Therefore, it is proposed, at least, to dedicate one more 5h-seminar for that purpose, and thus make it possible for students to manage this software autonomously.

- In order to consolidate the concepts taught during the initial training seminars, students could be asked to solve simple problems concerning the use of Mathcad software outside school hours.

6. REMARKS CONCLUSIONS

With the aim of improving the calculation of pumping power, an educational experience involving the management of Mathcad software was carried out with second-year chemical engineering students enrolled in the Fluid Flow course. The comprehensive teaching methodology included training courses on initiation to Mathcad, the delivery of a report (with valuable information about the theoretical considerations behind the phenomenon, the problem statement or the main indications to solve it by using Mathcad) and the creation of a meeting space supported by the Moodle virtual platform of the University of Huelva. Two student surveys were conducted separately after completing the training courses and solving the proposed pumping power problem by using Mathcad. Survey results clearly indicated that this computational tool significantly improved students' ability to solve the calculation of pumping power. The main reasons that students alleged for their decision are two: the mathematical difficulties are negligible and Mathcad allows them to understand the theoretical basis behind the pumping phenomenon. Students also submitted valuable suggestions for improving this educational experience, such as increasing the time spent on the training courses on initiation to Mathcad, which will be taken into account for oncoming experiences. Finally, it can be considered that Mathcad provides chemical engineering students with the ability for creating their own spreadsheets, so that they can apply this software to the resolution of other engineering problems in their academic or working life.

7. LIST OF SYMBOLS

V	velocity [m/s]
α	kinetic factor [-]
g	gravitational constant [m/s^2]
z	height [m]
P	pressure [Pa]
ρ	density [kg/m^3]
W	required energy [J/kg]
$\sum F$	friction energy losses [J/kg]
H	head [m]
L	length [m]
D	diameter [m]
f	friction factor [-]
ε	roughness [m]
Re	Reynolds numer [-]
μ	dynamic viscosity [Pa·s]
P_t	theoretical power pump [W]
P_d	drive pump [W]
$\dot{m}$	mass flow rate [kg/s]
Q	volumetric flow rate [m^3/s]
η_h	hydraulic efficiency [%]
η_m	motor efficiency [%]
η_t	total efficiency [%]
$\sum F_i$	internal energy losses due to the pump [J/kg]

8. ACKNOWLEDGEMENTS

This work has been possible thanks to the Teaching Innovation Project entitled "Mejoras en el proceso de enseñanza-aprendizaje del grado en Ingeniería Química Industrial a través de metodologías docentes asistidas por ordenador en la resolución de problemas" granted by the University of Huelva. Authors wish to acknowledge the indispensable contribution of the second-year chemical engineering students enrolled in Fluid Flow course corresponding to the 2017/2018 academic year. A.A. Cuadri especially want to thank D. Antonio López Pérez for improving the English of the manuscript.

9. DECLARATION OF INTEREST

None

10. REFERENCES

Abbas, A., Al-Bastaki, N., 2002. The use of software for ChE education: Students' evaluations. Chem. Eng. Educ. 36, 236-241.

Barak, M., 2018. Are digital natives open to change? Examining flexible thinking and resistance to change. Comput. Educ. 121, 115-123.

Calvo, L., Prieto, C., 2016. The teaching of enhanced distillation processes using a commercial simulator and a project-based learning approach. Educ. Chem. Eng. 17, 65-74.

Castier, M., Amer, M.M., 2011. XSEOS: An evolving tool for teaching chemical engineering thermodynamics. Educ. Chem. Eng. 6, e62-e70.

Golman, B., 2016. Transient kinetic analysis of multipath reactions: An educational module using the IPython software package. Educ. Chem. Eng. 15, 1-18.

Juuso, E.K., 2018. An advanced teaching scheme for integrating problem-based learning in control education. Open Eng. 8, 41-49.

Li, X., Huang, Z.J., 2017. An inverted classroom approach to educate MATLAB in chemical process control. Educ. Chem. Eng. 19, 1-12.

Mahecha-Botero, A., Reaume, S., Grace, J.R., Ellis, N., 2011. Independent research as a teaching tool in graduate chemical reaction engineering. Case study: modelling isomerization of unsaturated fatty acids with catalyst deactivation. Educ. Chem. Eng. 6, e1–e9.

Mejri, S., Binous, H., Mahgoub, K., Bellagi, A., 2018. A model parameter estimation method using MATHEMATICA© applied to transient chemical engineering processes. Comput. Appl. Eng. Educ. 26, 1405-1421.

National Research Council (NRC) (2012). Education for life and work: Developing transferable knowledge and skills in the 21st century. Committee on defining deeper learning and 21st century skills. In J. W. Pellegrino, & M. L. Hilton (Eds.). Board on testing and assessment and board on science education, division of behavioral and social sciences and education. Washington, DC: The National Academies Press.

Organization for Economic Cooperation and Development (OECD) (2015). Students, computers and learning – making the connection. Paris: OECD Publishing.

Ospino, J., Sánchez, M.E., Secchi, A.R., 2017. Implementation of a block-oriented model library for undergraduate process control courses in EMSO simulator. Educ. Chem. Eng. 18, 45-57.

Shacham, M., Brauner, N., 2015. A hundred years of chemical equilibrium calculations- The case of ammonia synthesis. Educ. Chem. Eng. 13, 17-23.

Height

$z1 := 0\,m$

$z2 := 15\,m$

Pressure

$P1 := 110000\,\frac{N}{m^2}$

$P2 := 125000\,\frac{N}{m^2}$

$\rho := 705\,\frac{kg}{m^3}$ **Density**

$\mu := 0.015\,\frac{kg}{m \cdot s}$ **Viscosity**

$L := 2000\,m$ **Length**

$di := 0.20\,m$ **Internal diameter**

$\varepsilon := 0.0004\,m$ **Roughness**

$Fi := 20\,\frac{J}{kg}$ **Intenal energy losses inside the pump**

Figure 1. A portion of the Mathcad spreadsheet including all known variables values.

$$S := \frac{\pi \cdot di^2}{4} = 0.031\,m^2$$ **Flow area**

Velocity (V), Reynolds number (Re) and friction factor (f) as a function of volumetric flow rate (Q):

$$V(Q) := S^{-1} \cdot Q$$

$$Re(Q) := \frac{\rho \cdot V(Q) \cdot di}{\mu}$$

$$f(Q) := \left[\frac{1}{-4 \cdot \log\left[\left(\frac{1}{3.7065} \right) \cdot \left(\frac{\varepsilon}{di} \right) + \frac{-5.0452}{Re(Q)} \cdot \log\left[\frac{1}{2.8257} \left(\frac{\varepsilon}{di} \right)^{1.1098} + \frac{5.8506}{Re(Q)^{0.8981}} \right] \right]} \right]^2$$

Points of the operation line can be calculated from V and f values:

$$Hoperation\_line(Q) := \left[(z2 - z1) + \frac{1}{\rho \cdot g}(P2 - P1) + \frac{\left(\frac{2 \cdot f(Q) \cdot L \cdot V(Q)^2}{di} + Fi \right)}{g} \right]$$

From Q values their corresponding V, Re, f, and, finally, points of the operation line are calulated:

$$Q := 0.01 \frac{m^3}{s}, 0.02 \frac{m^3}{s} .. 0.1 \frac{m^3}{s}$$

Q = ($\frac{m^3}{s}$)	V(Q) = ($\frac{m}{s}$)	Re(Q) =	f(Q) =	Hoperation_line(Q) = (m)
0.01	0.318	$2.992 \cdot 10^3$	0.011	21.545
0.02	0.637	$5.984 \cdot 10^3$	$9.474 \cdot 10^{-3}$	27.04
0.03	0.955	$8.976 \cdot 10^3$	$8.657 \cdot 10^{-3}$	35.308
0.04	1.273	$1.197 \cdot 10^4$	$8.17 \cdot 10^{-3}$	46.222
0.05	1.592	$1.496 \cdot 10^4$	$7.841 \cdot 10^{-3}$	59.715
0.06	1.91	$1.795 \cdot 10^4$	$7.6 \cdot 10^{-3}$	75.746
0.07	2.228	$2.094 \cdot 10^4$	$7.415 \cdot 10^{-3}$	94.29
0.08	2.546	$2.394 \cdot 10^4$	$7.268 \cdot 10^{-3}$	115.327
0.09	2.865	$2.693 \cdot 10^4$	$7.148 \cdot 10^{-3}$	138.844
0.1	3.183	$2.992 \cdot 10^4$	$7.047 \cdot 10^{-3}$	164.83

Figure 2. A portion of the Mathcad spreadsheet with the procedure for obtaining the points of the operation line.

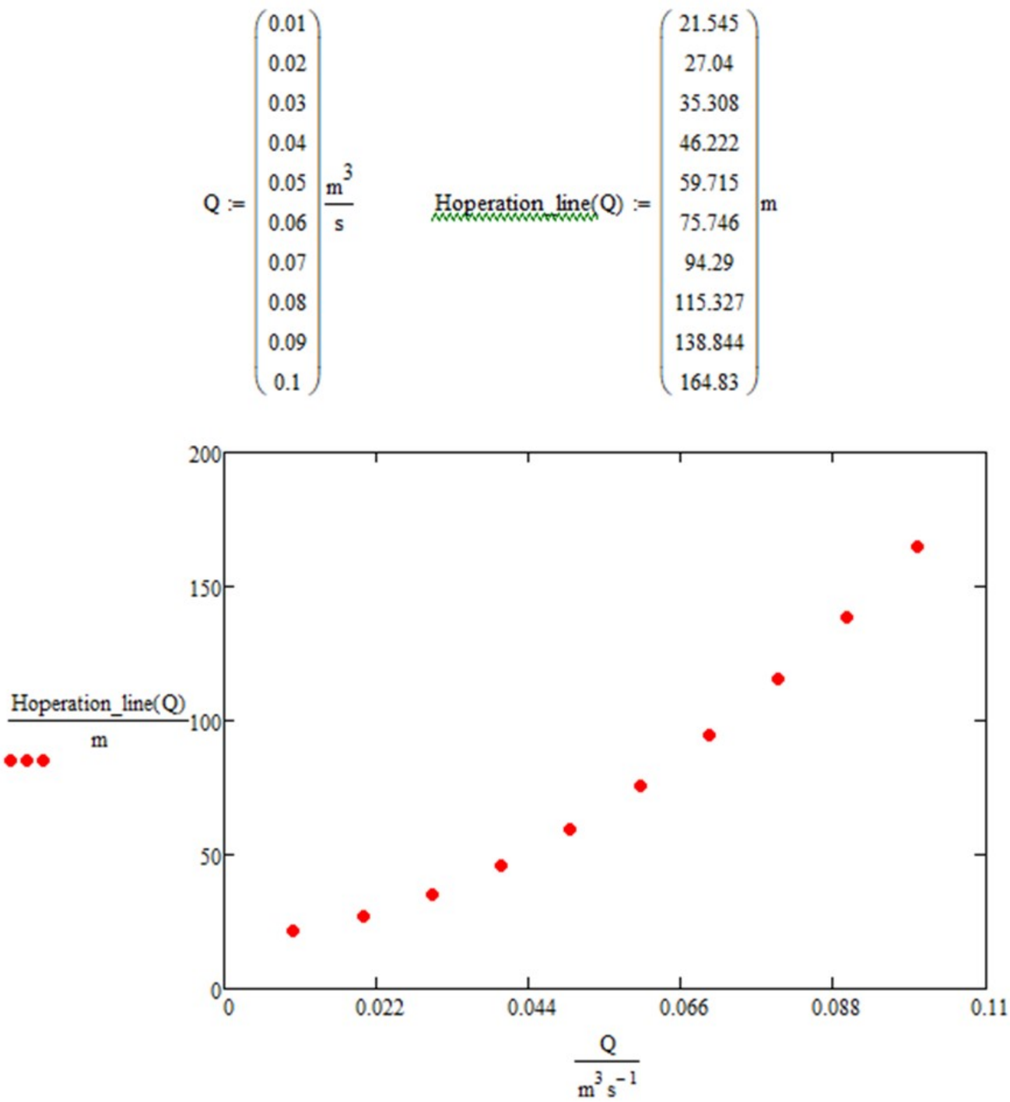


Figure 3. A portion of the Mathcad spreadsheet with a figure including the operation line.

Cubic spline vector:

v := cspline(Q,Hoperation_line(Q))

Interpolation function:

f(x) := interp(v,Q,Hoperation_line(Q),x)

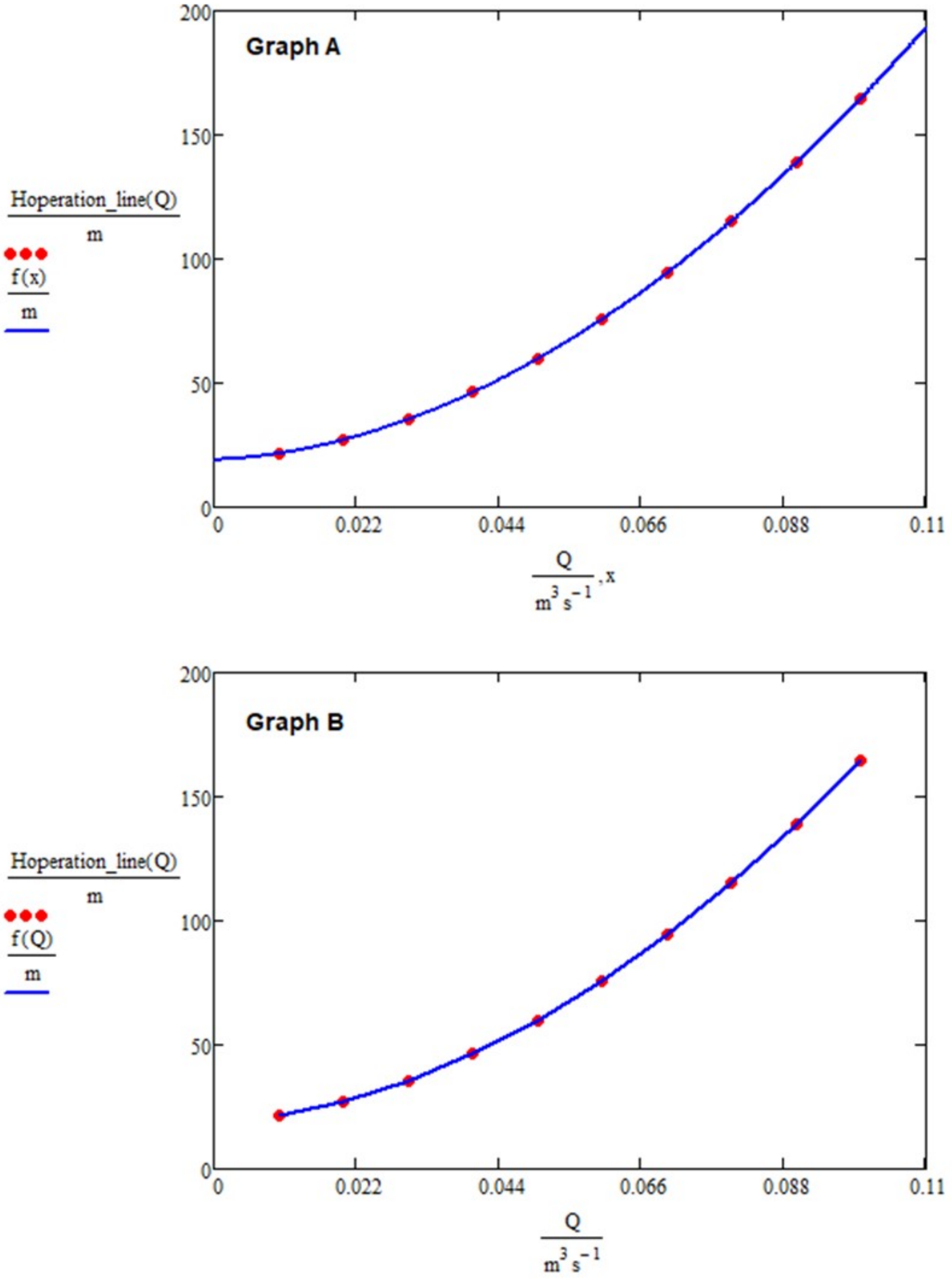


Figure 4. A portion of the Mathcad spreadsheet with the procedure for adjusting the operation line to a spline interpolation function.

H vs. Q characteristic curve:

$$\text{Hcharacteristic\_curve}(Q) := 122\text{m} - \left(115\,\frac{\text{s}}{\text{m}^2}\right)Q - \left(5560\,\frac{\text{s}^2}{\text{m}^5}\right)Q^2$$

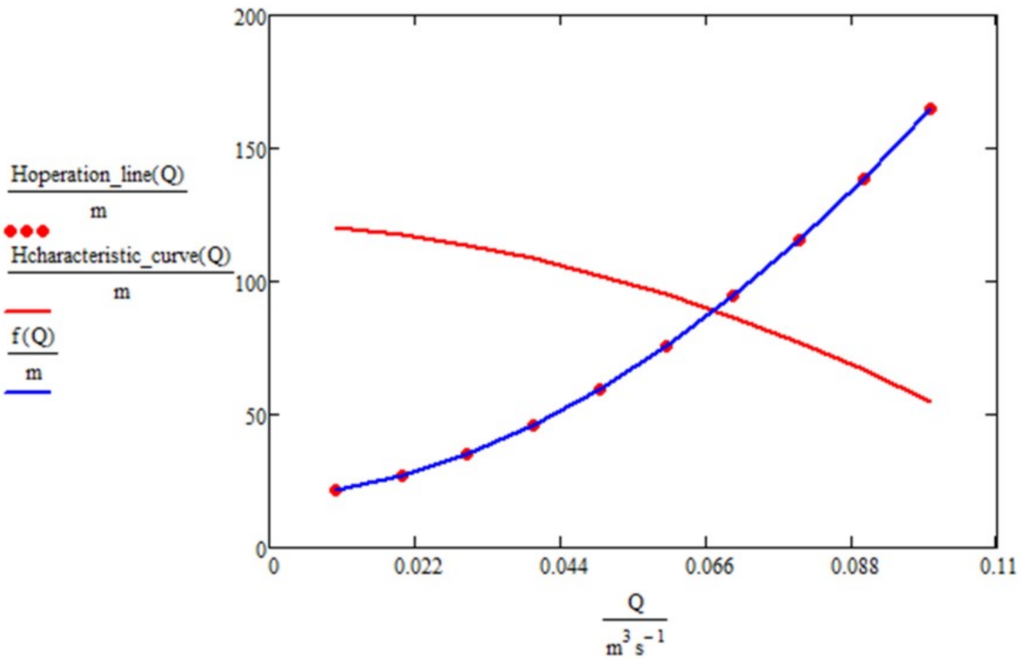
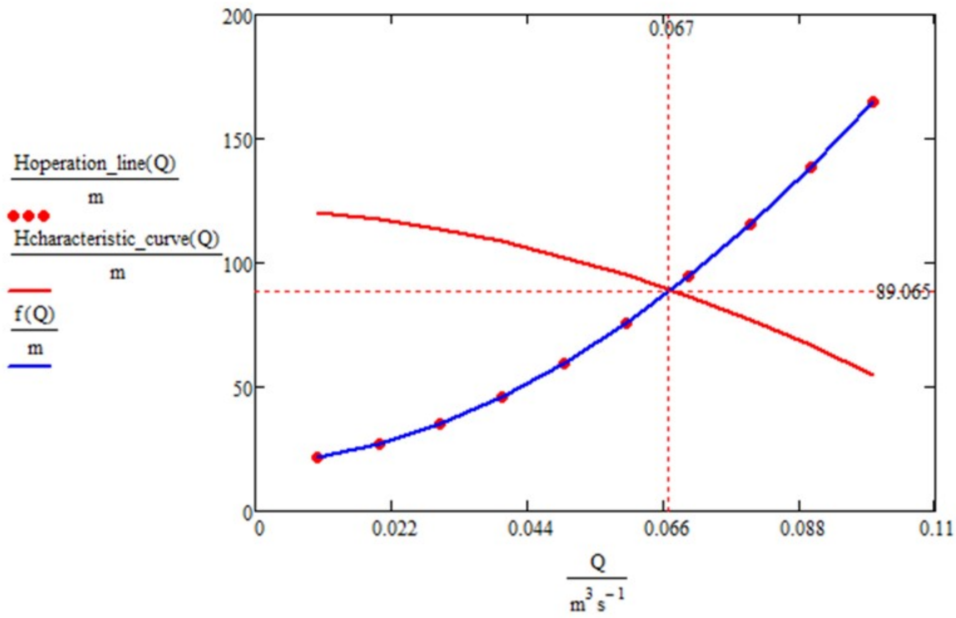


Figure 5. A portion of the Mathcad spreadsheet with a figure including both operation line and the H vs. Q characteristic curve.



Guess value:

$Q := 0.04 \frac{m^3}{s}$

System of equations:

Given

Hcharacteristic_curve(Q) = f(Q)

Solution:

Q_solution := Find(Q)

$Q\_solution = 0.067 \frac{m^3}{s}$

Checking the solution:

Hcharacteristic_curve(Q_solution) = 89.065 m   f(Q_solution) = 89.065 m

Finally, the drive power (P_d) is calculated:

$$\eta(Q) := \frac{33 + \left(2376 \cdot \frac{s}{m^3}\right) \cdot Q - \left(34614 \cdot \frac{s^2}{m^6}\right) \cdot Q^2}{100}$$

$\eta(Q\_solution) = 0.361$

H_solution(Q_solution) := Hcharacteristic_curve(Q_solution)

$W\_solution := H\_solution(Q\_solution) \cdot g = 873.428 \frac{m^2}{s^2}$

$$Pd := \frac{(W\_solution - Fi) \cdot \rho \cdot Q\_solution}{\eta(Q\_solution)} = 1.122 \times 10^5 \, W$$

Figure 6. A portion of the Mathcad spreadsheet with the procedure for calculating the drive power.

TRAINING COURSES ON INITIATION TO MATHCAD					
1-Very low ; 2-Low ; 3-High ; 4-Very high					
		1	**2**	**3**	**4**
Q1	Prior knowledge of Mathcad				
Q2	Degree of teacher's involvement				
Q3	Degree of teacher's knowledge of Mathcad				
Q4	The teacher satisfies the doubts raised				
Q5	The content of courses are adjusted to what was expected				
Q6	I am able to use Mathcad autonomously				
Q7	The courses require more time				
Q8	This software is difficult to use				
Q9	Your interest in Mathcad is higher than before the courses				
Q10	Global evaluation				
	Some comments:				

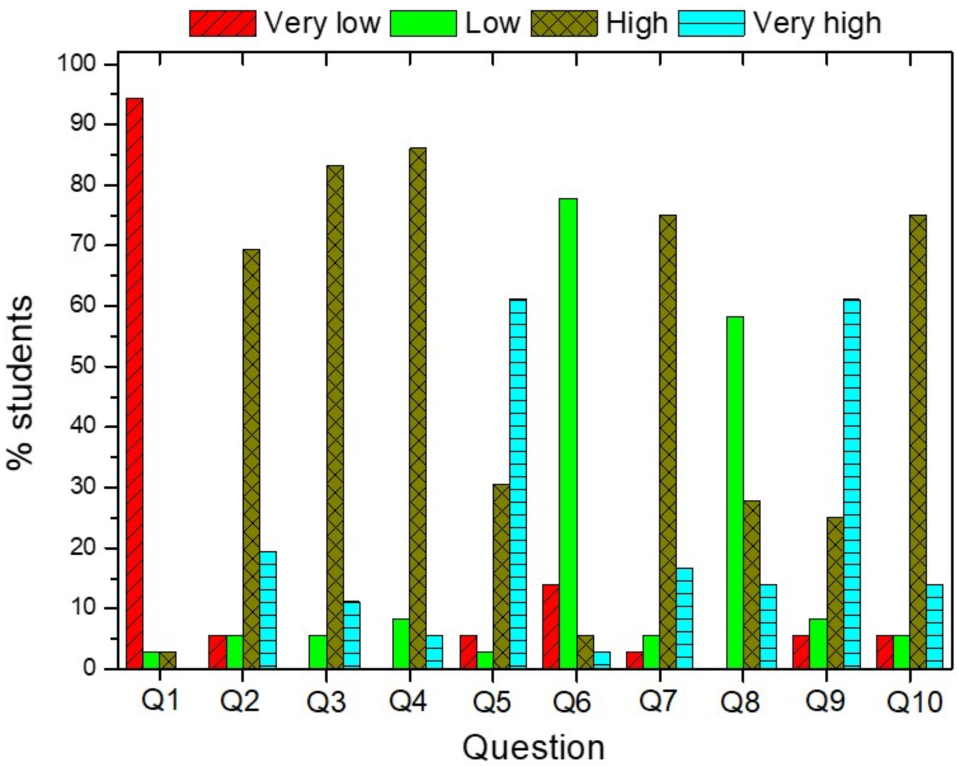


Figure 7. Student survey questions about the training courses on initiation to Mathcad and their corresponding responses.

CALCULATION OF PUMPING POWER BY USING MATHCAD					
1-Strongly disagree ; 2- Disagree ; 3-Agree ; 4- Strongly agree					
		1	**2**	**3**	**4**
Q1	I prefer to perform this exercise by using Mathcad instead of the traditional procedure				
Q2	With the use of Mathcad, I can better understand the theoretical foundation of this engineering problem				
Q3	With the use of Mathcad, I save time of mathematical calculation				
Q4	Mathcad allows me to study how the different input variables affect the final result				
Q5	Mathcad allows me to improve my skills in the management of this type of software				
Q6	I would like to continue deepening and knowing new functions of Mathcad				
Q7	The knowledge acquired from Mathcad is enough to solve other engineering problems related with other subjects				
Q8	I believe that Mathcad will be very useful for my future work				
Q9	I consider that Mathcad motivates me to study other problems related to Fluid Flow				
Q10	Global evaluation				
	Some comments:				

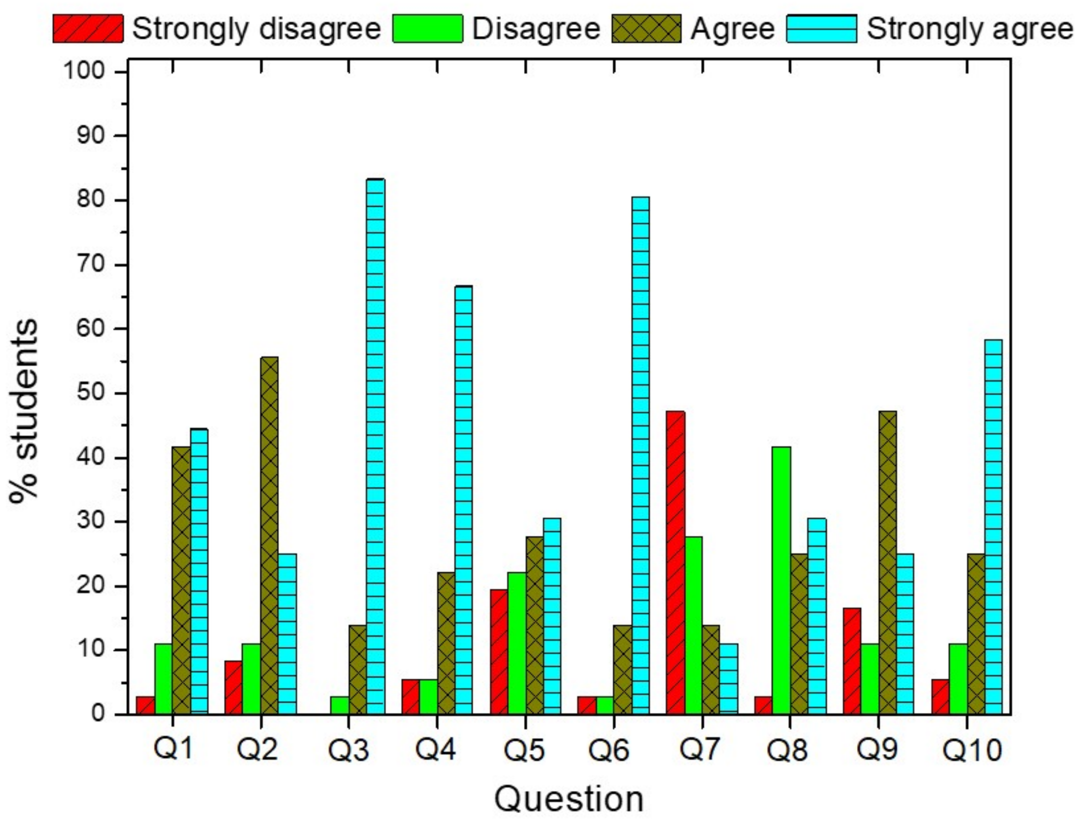


Figure 8. Student survey questions about the calculation of pumping power by using Mathcad and their corresponding responses.