Presentation of the First Law of Thermodynamics for Open Systems

Using a Graphical User Interface

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Abstract

This paper presents the development of two cases of the first law of thermodynamics in open systems through the use of a registered graphical user interface (GUI) made in Matlab, as a complementary tool in the process of teaching undergraduate students of mechanical engineering from Universidad del Atlántico. Several experimental correlations reported in the literature for solving problems were considered. It was used the thermodynamic equations in the development of the algorithm of the software to perform energy analysis in a practical, interactive and user-friendly way, allowing students to identify the general behavior in nozzles and heat exchangers when they operate under specific conditions. It was obtained the exit velocity profiles as a function of changes in temperature and pressure in nozzles. In heat exchanges, the total heat transferred and the difference in temperature for the cold fluid is linearly dependent on the difference in temperature of the hot fluid with a higher efficiency when water is the cold fluid.

Keywords: Matlab, software, Thermodynamic, Energy Analysis, Control Volumes
1. Introduction

The use of computational tools has had an exponential growth in many scientific fields, with higher use in the areas of engineering becoming a crucial complement in the development of their courses using simulations as an interesting alternative in the use of laboratories [1]. Although it is true that the laboratories let students interact with real situations, it has been demonstrated that students find great interest and motivation when implementing software as a teaching complement [2]. It had a high impact on the development of teaching thermodynamics from the traditional method to one more versatile method. With the use of simulations, students get more participation in classes [3, 4]. Comparative studies were made on a group of students trained with interactive teaching, quantifying the improvement of their performance [5] through an analysis of variance. A required topic studied in mechanical engineering undergraduate students is the first law of thermodynamics, which is the classical expression to evaluate the conservation of energy in open systems. Nozzles in pipes and heat exchangers are a particular example of the most important open systems used in all the engineering sectors in the daily life. Some software such as Aspen, ChemCAD, CTherm, Pro/II, Simsci has been created to simulate the mentioned systems, etc. However, they have industrial purposes with a high degree of complexity, making it difficult to use them for teaching purposes, [6-8]. Some software helps educational purposes such as COMSOL Multiphysics, ANSYS Fluent, etc. [9-11]. Though, they have a level of complexity only for graduate students, and not for undergraduate students. Considering the great importance of open systems in engineers, this study aimed at using a graphical user interface made in Matlab to simulate the thermodynamic process of some important case studies in open systems. The systems studied were the velocity profile in nozzles, and the total heat transferred in a heat exchanger as a function of the inlet and outlet temperatures of the different fluids used such as water, oil, ethylene glycol, and air. It gives students the ability to explain the phenomena in the process.

2. Methodology

2.1 Presentation of the software

The software VolControl was used as shown in figure 1 to make the mass and energy analysis of open systems under a regime of stationary flow. It was run the software for the case of a nozzle and a heat exchanger under different operating conditions. The software gives the possibility to choose a different type of fluid, where water, oil, ethylene glycol, and air were selected.
2.2 Basic equations

All equations used in the software are presented below, [12, 13]. For the analysis of stationary flow devices, it is necessary to perform the mass balance, resulting in equation (1).

\[ \sum \dot{m}_i = \rho_1 V_1 A_1 = \rho_2 V_2 A_2 \] (1)

and the energy balance, see equation (2)

\[ \dot{Q}_{in} + \dot{W}_{in} + \sum_{in} \dot{m} \theta = \dot{Q}_{out} + \dot{W}_{out} + \sum_{out} \dot{m} \theta \] (2)

Where \[ \theta = h + \frac{v^2}{2} + gz \] (3)

Considering that changes in potential energy are very small compared to the changes in kinetic energy in devices of stationary flow, it is obtained equation (4)

\[ \dot{Q}_{in} + \dot{W}_{in} + \dot{m}(h_1 + \frac{v_1^2}{2}) = \dot{Q}_{out} + \dot{W}_{out} + \dot{m}(h_2 + \frac{v_2^2}{2}) \] (4)
3. Results and discussion

It was made a comparative study of the results obtained by the undergraduate students in Mechanical Engineering and the calculations of the manual way using the texts of literature in classic Thermodynamics. The parametric results are presented only for the cases of the study of nozzle and heat exchanger.

3.1 Validation of the software VolControl

It was done a comparative analysis of the average results obtained by 33 students to validate the software. The case studies were solved manually and with the software, obtaining the following errors shown in Table.

<table>
<thead>
<tr>
<th>Case study</th>
<th>Parameter</th>
<th>GUI</th>
<th>Manual</th>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nozzle</td>
<td>$V_2$ (m/s)</td>
<td>240.006</td>
<td>239.999</td>
<td>0.006</td>
</tr>
<tr>
<td>Nozzle</td>
<td>$A_2$ (m$^2$)</td>
<td>59.8246</td>
<td>59.7400</td>
<td>0.142</td>
</tr>
<tr>
<td>Heat exchanger</td>
<td>$\dot{Q}$ (kW)</td>
<td>20100</td>
<td>20100</td>
<td>0.000</td>
</tr>
<tr>
<td>Heat exchanger</td>
<td>$T_4$ ($^\circ$C)</td>
<td>156.172</td>
<td>156.170</td>
<td>0.001</td>
</tr>
</tbody>
</table>

The small errors are attained to significant figures when making the math operations manually. It can be seen that the software is highly reliable.

3.2 Nozzle case study

It was analyzed the behavior of a nozzle operated with water vapor for the following operating conditions, $P_1 = 300$ Kpa, $T_1 = 200^\circ$C, $V_1 = 45$ m/s, $A_1 = 110$ cm$^2$ and $\dot{Q} = 1.5$ kW.

Figure shows that the change in pressure affects the velocity of the fluid at the exit of the nozzle when working with steam because the enthalpy of the steam not only depends on the temperature, but also on the pressure. It can be seen that for the same $\Delta T$, the exit velocity decreases when $\Delta P$ increases. However, the variation of the exit velocity decreases at high $\Delta T$. In the other hand, the output area $A_2$ of the steam nozzle increases when $\Delta P$ increases reaching its highest value in the lowest $\Delta T$. Though, the differences between $A_2$ and $A_1$, for all the values of $\Delta P$, decrease when $\Delta T$ increases. It has to be considered that for values of $A_2/A_1$ higher than 1, the nozzle behaves like a diffuser.
3.3 Heat exchanger case study

The behavior of a heat exchanger was analyzed using water as a cold fluid. The hot fluid outlet temperature was varied every 50°C between from 100°C to 400°C. Different fluids were studied in the hot line (water, oil, ethylene glycol, air, and gas). The following operating conditions were used, $T_1 = 500°C$, $T_2 = 60°C$, $\dot{m}_h=50$ kg/s and $\dot{m}_c = 50$ kg/s.

It can be seen in Figure 3 that the total heat transferred $\dot{Q}$, and $\Delta T$ for the cool fluid are linearly dependent on the $\Delta T$ for the hot fluid. This effect is higher for water than for the rest of the fluids because of the physical properties. This plot helps to choose what kind of fluid to use when it is desired to remove a specific amount of heat.
Figure 3. Results from the analysis of the heat exchanger with oil as a cold fluid.

The same study was made with oil as cold fluid, see figure 4. It can be seen that a higher $\Delta T_{\text{cool}}$ (using oil) is obtained for the same $\Delta T$ hot when compared with water for the same amount of heat transferred. It happens because of the difference between the specific heat of the water and the oil. This kind of comparison made by simulations is helpful at the time of designing heat exchangers because it let to take decisions depending on the limits of temperatures required in a process.

4. Conclusions

It was made a study of energy transfer and increase in velocity done in open systems using an educational graphical user interface developed in Matlab. The systems used were a heat exchanger, and a Nuzzle. The heat exchanger used water and oil as a cold fluid, and the nozzle used water vapor as working material. During the study of the nozzle a peculiar behavior was presented, under specific operating conditions it was observed that the design of the nozzle behaved as a diffuser, because the relation $(A_2/A_1)$ was higher than 1. Therefore restrictions should be taken in the operating conditions when designing a nozzle.

In the heat exchangers, the total heat transferred $Q$, and $\Delta T$ for the cool fluid are linearly dependent on the $\Delta T$ for the hot fluid because the specific heat remains almost constant in the range of 450C. However, this effect was higher for water than for the rest of the fluids used because of their physical properties letting to choose the type of hot fluid to use when it is desired to remove a specific amount of heat in a line of a process.

The use of the Graphical User Interface (GUI) increases the effectiveness of a thermodynamic class because it allows students to have a better understanding of the phenomena happening within the devices operating in a steady flow. It allows the teacher to evaluate different competencies increase the intellectual level of students.
References


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