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Feiza Memet

Attempts for a Better Understanding of Entropy by the Students in CMU

Regarding thermodynamics, the perception of students is that unlike the first law, the second law has not simple statements. Despite of this, the first two laws are related to each other and their combination shows the influence of entropy on energy. The understanding of the second law is the path to student knowledge related to the increase in entropy and the decrease of the capacity of energy to do useful work or energy. This paper describes an experiment carried out in Constanta Maritime University (CMU), with students enrolled in Electromechanics Faculty, in the second year of study, which reveals the need to enrich the traditional course of Thermodynamics, in order to increase the ability of students to deal with the second law and the concept of entropy.

Keywords*: entropy, second law, understanding, volunteers*

1. Introduction

Knowledge in Thermodynamics plays an important role for the rigorous understanding of natural phenomena and working of thermal and energy systems of different kind (thermal engines, power plants, refrigerators, etc).

Thermodynamics is a vital discipline of the mechanical engineering curricula, future professionals being able to compute changes in thermodynamic properties, determine working conditions for thermodynamic cycles in order to improve power or efficiency, design plants for improved efficiency by the help of thermodynamic reasoning, develop experimental assessment of thermal and energy systems, assess in manual or computational manner properties of fluids by the help of the equation of state, property tables or charts.

Thermodynamics is not only an essential topic in the curricula of future engineers, it is also a difficult discipline for many students: it is seen as being composed exclusively of equations and abstract concepts (Carson and Watson, 2002). For this type of students, to pass examination it is similar with assuming arid theory and solving difficult thermodynamic problems. Learning and understanding thermodynamics is a challenging task for engineering students, sometimes even after going through it more times, confusion being often related with topics as work, heat, internal energy, enthalpy, entropy, laws of thermodynamics (Mulop et al, 2010).

In CMU, entropy is introduced to students enrolled for Electromechanics Faculty, during their first course of Thermodynamics.

This course is delivered during their second year of study and it is structured on 42 hours of courses, 14 hours of seminar and 14 hours of laboratory.

The concept of entropy is included in the chapter number 5, of our syllabus, which is dedicated to the second law of Thermodynamics; its length is of 8 hours. The content of this chapter includes cyclic transformations, thermal efficiency and coefficient of performance, Carnot cycle (direct and reversed), entropy, formulations of the second law, entropic diagrams, maximum technical work.

First law of thermodynamics and its concepts are understood without too much difficulty, students assimilating easily that energy can be changed from one form to another, but it cannot be created or destroyed; the first law is also known as the law of conservation and states that energy is always conserved.

It is not the case of the second law of thermodynamics which permits to assess how well an energy system acts in terms of quality of the energy. The second law asserts that a process occurs in a certain direction only.

Also according to the second law, the mutual change of heat into work during a process is not possible, but its opposite can occur. A process occurs only if it satisfies the first law as well the second law of thermodynamics.

The first law is not able to describe irreversibility; this is the advantage of the second law.

Entropy is introduced in the context of irreversible processes and denotes the degree to which finite time processes are irreversible.

Mathematically, entropy is given by the rate between the heat exchanged and the temperature at which that exchange takes place.

Entropy is an extensive state variable. For an isolated closed system, its entropy increases with any physical action or transformation taking place inside it. It is impossible to get an entropy decrease in an isolated system; when this type of system reaches a state of internal equilibrium, its entropy is maximized.

There are several statements related with entropy:

- a small object contains less entropy,
- an object having a low temperature contains less entropy,
- entropy flows naturally from a place with a high temperature to another one with a lower temperature,
- a temperature difference is a driving force for an entropy stream,
- entropy transfer between a place with a low temperature to another one with a higher temperature is possible by the help of a heat pump,

- the lowest temperature of an object is –273.15°C; at this temperature this object cannot contain entropy,
- entropy can be created, but cannot be destroyed,
- entropy is produced in irreversible processes.

This paper is dedicated to an approach in supporting students in CMU to learn and understand the concept of entropy, based on an experiment carried out by the help of volunteers.

2. Methods and materials

It is accepted the fact that the concept of entropy is idealized and abstract, being difficult to establish a connection between it and daily experiences (Haylund et al, 2010).

From the above discussions results once again the explanation of the fact that students in CMU (and not only) face difficulties in dealing with the concept of entropy. Such a situation requires efforts to be done to find an approach able to help our students to overcome this obstacle.

In this respect, from a group of students of 25 persons was selected a group of 8 volunteers. The volunteers accepted their participation in two additional extra classes (four hours) dealing with the second law of thermodynamics.

With these students were discussed topics, which normally are not included in the traditional teaching carried out in CMU.

The additional extra classes were scheduled in the period of semester dedicated to the teaching of the second law, in the traditional manner.

The first step is to combine discussion of first and second laws when assessing a refrigeration system.

Students should be aware of the fact that an accurate engineering analysis of a system, especially of a new one, considering only one of the laws is not possible; future specialists must use as tools when designing engineering systems both the first and second laws of thermodynamics.

Secondly, it is important to connect more tightly entropy with energy.

It is needed to insist more on the concept of energy which indicates the influence of entropy on energy.

In brief, exergy is the measure of the quality level of the energy. Students must be familiar whit the fact that entropy degrades the ability of energy to produce useful work.

Third, apart from natural science domains, entropy has also been used to explain situations specific to other non technical fields as economics, art, religion, medicine, etc.

It is useful for student’s better understanding to encourage familiarization with these interesting aspects.

The new opportunities of improving a traditional thermodynamics course mentioned above were exposed to the group of volunteers, starting with one presentation dealing with the analyze of a vapor compression refrigeration system based on the first and second laws of thermodynamics (Stanciu et al, 2011).

From first law standpoint, the performance of such system is given by COP (Coefficient of Performance), which is expressed by the rate between the refrigerating cooling effect and the compressor power input, while from the second law perspective, the performance is given by the exergetic efficiency, η_{ex}, calculated with the rate between exergy in product (Ex_p) and the exergy of fuel (Ex_F).

The single stage vapor compression refrigeration system is composed by four main parts: compressor, condenser, throttling valve and evaporator.

Each part is seen as a control volume and the whole system as a control mass.

By applying the first law for to a control volume results:

$$\frac{dE_{CV}}{d\tau} = \sum_i \left(h + \frac{w^2}{2} + gz \right)_i \dot{m}_i - \\ - \sum_o \left(h + \frac{w^2}{2} + gz \right)_o \dot{m}_o + \dot{Q}_{CV} - \dot{W}_{CV} \quad (1)$$

where:

E – system energy,

τ – time,

h – specific enthalpy of the refrigerant,

$\frac{w^2}{2}$ – specific kinetic energy,

gz – specific potential energy,

$\dot{m}$ – refrigerant mass flow rate,

$\dot{Q}$ – heat flux change of the control volume with its surroundings,

$\dot{W}$ – power change of the control volume with its surroundings,

i / o – subscripts referring to inlet and outlet.

For steady state operation and by neglecting the changes of kinetic and potential energies, the above equation can be written as:

$$\dot{Q}_{CV} - \dot{W}_{CV} = \sum_o (\dot{m}h)_o - \sum_i (\dot{m}h)_i \quad (2)$$

Equation (2) is written for all the four main components of the system considered. Thus, result the heat flux in the heat exchangers and the work input to the compressor.

Finally, it is possible to assess the energetic efficiency, or the first law efficiency, or COP:

$$COP = \frac{h_{oev} - h_{iev}}{h_{ok} - h_{ik}} \tag{3}$$

where:

ev / k – subscripts referring to evaporator and compressor.

By applying the second law to a control volume, results the entropy generation in the system as follows:

$$\dot{S}_{gen} = \frac{dS_{CV}}{d\tau} + \sum_{o} (\dot{m}s)_o - \sum_{i} (\dot{m}s)_i - \sum_{j} \left(\frac{\dot{Q}_j}{T_j} \right)_{ext} \tag{4}$$

where:

$\frac{dS_{CV}}{d\tau} = 0$ – for a steady state operation,

s – specific entropy.

Equation (4) is then applied to the all four parts of the system.

The exergetic analysis relies on writing the exergetic balance equation for a control volume as:

$$\begin{aligned} \frac{dEx_{CV}}{d\tau} &= \sum_{i} \dot{E}x_{Qi} - \left(\sum \dot{W} - p_0 \frac{dV}{d\tau} \right) + \\ &+ \sum_{i} (\dot{m}ex)_i - \sum_{o} (\dot{m}ex)_o - \sum I \end{aligned} \tag{5}$$

where:

Ex – total exergy,

Ex_{Qi} – heat exergy rate,

ex – specific exergy,

I – exergy destruction rate,

o – subscript referring to extensive parameters of the system brought in the restrictive dead state,

p_o – standard pressure of the environment (p_o = 1 bar).

For the specific exergy and heat exergy rate are given the relations bellow:

$$ex = (h - h_o) - T_o (s - s_o) \tag{6}$$

$$\dot{E}x_Q = \dot{Q} \left(1 - \frac{T_o}{T_{boundary}} \right) \tag{7}$$

where:

T_o – standard temperature of the environment (T_o = 299.15K).

The exergy destruction rate is evaluated by the help of Guy-Stodola theorem:

$$I = T_o \dot{S}_{gen} \quad (8)$$

In the case of steady state operation, equation (5) becomes equation (9), which will be applied to each of four component parts of the system.

$$\sum I = \sum_i (\dot{m}ex)_i - \sum_o (\dot{m}ex)_o + \sum_i \dot{E}x_{Qi} - \sum \dot{W} \quad (9)$$

The total exergy destruction rate (I_t) is found by summing the exergy destruction rates of each device.

The exergetic efficiency, or the second law efficiency can be found now as:

$$\eta_{ex} = 1 - \frac{I_T}{Ex_F} \quad (10)$$

where the fuel exergy rate is given by the consumption to the compressor.

Regarding the penetration of entropy in non engineering disciplines, volunteers found during the extra classes that a system in which it is developed an economic activity, for example, it is featured by the interaction between natural and human components, so, in order to produce economic goods, the economic process combines human inputs (knowledge) and natural inputs (matter / energy) (De Pascale, 2012).

In is already known from the classic course that entropy applies to energy and matter.

During the extra classes it is discussed with the volunteers that economic growth, featured by the increase of energy and matter flows through the society, leads to a progressive depletion of available energy and matter and to the increase of entropy.

3. Results and discussions

When the chapter dedicated to the second law was completed both from classic course and additional classes' point of view, the whole group was tested.

The set of questions was as follows (Jacobs, 2014), (Dincer and Rosen, 2012):

A. Mark the correct answer:

1. The distinction between reversible and irreversible process is in relation with:

a. the second law of thermodynamics

b. the first law of thermodynamics

c. both the first and second laws

correct answer: a

2. Entropy is a concept introduced by:
a. the second law of thermodynamics
b. the first law of thermodynamics
c. the state principle of thermodynamics
correct answer: a

3. The entropy of a system can increase when:
a. takes place a mixing of substances
b. a change of state takes place from solid to liquid state
c. it absorbs energy
correct answer: c

4. All spontaneous processes proceed to:
a. minimize entropy
b. maximize entropy
c. keep constant entropy
correct answer: b

5. The entropy generation associated with a process or cycle due to irreversibilities is given by
a. $S_{gen} = \Delta S_{system} + \Delta S_{surroundings}$
b. $S_{gen} = \Delta S_{system} - \Delta S_{surroundings}$
c. $S_{gen} = \Delta S_{surroundings} - \Delta S_{system}$
correct answer: a

6. For an irreversible process, energy is conserved and
a. its exergy remains the same
b. its exergy increases
c. its exergy decreases
correct answer: c

B. Assign "false" or "true" to the following statements:
1. Values of entropy generation less than zero are impossible
correct answer: true
2. By the use of the second law can be assessed the maximum work which can be produced
correct answer: true
3. The exergy method of analysis is not able to exceed the restrictions of the first law
correct answer: false
4. Exergy efficiencies are an indicator of approach to irreversibility
correct answer: false

The results of the questionnaire are given in Table 1.

Table 1. Results of the questionnaire aiming better understanding of entropy concept

Question	Correct answer		Wrong answer	
	Volunteers	Rest	Volunteers	Rest
A1	8	14	-	3
A2	8	14	-	3
A3	8	13	-	4
A4	8	12	-	5
A5	7	10	1	7
A6	8	11	-	6
B1	8	11	-	6
B2	8	10	-	7
B3	8	9	-	8
B4	8	4	-	13

From Table 1 it is seen that the volunteers solved successfully the questionnaire, only one volunteer failed at question A5.

Last years' experience has shown that students showing interest for the classic thermodynamics course have no difficulty in finding the right answer for questions A1-A4 and statements B1-B2.

From Table 1 result that the situation is the same for the presented experiment: most of the students which have not accepted to attempt to the extra classes could reply to questions A1-A4 and statements B1-B2.

Finding the correct answer for question A5 and A6 and statements B3 and B4 is stimulated by the participation to the mentioned additional extra classes, statistics on volunteers being more than suggestive. Thus, 88% of the volunteers found correct answer for question A5, while 59% of the rest of the students could find it.

On question A6, the analysis shows that 100% of the volunteers could deal with this question, while from the rest of the students, only 65%.

Statistics on statement B3 shows that 100% of the volunteers were successful, while from the rest, only 53%; statistics on statement B4 indicates that all the volunteers had correct answers, while the rest of the students faced difficulties (only 24% were able to find the right answer).

4. Conclusion

The Thermodynamics course provides to future engineers principles for the assessment of different designs, but for many students to pass this discipline is an unpleasant challenge.

This paper describes the manner in which in Constanta Maritime University a classical Thermodynamics course is proposed to be enriched, for a better understanding of the concept of entropy and, default, of the second law.

In this respect, an experiment was carried out with students enrolled in the second year of study, Electromechanics Faculty.

From a group of 25 students were selected 8 volunteers which agree to participate to two additional extra classes during which was presented a new approach related to the second law of thermodynamics dealing with: the assessment of a refrigeration system based on first and second law of thermodynamics, a better connection between entropy and energy, seen in the same analysis, and the application of entropy in other fields than thermodynamics, as economics.

When the chapter dedicated to the second law was finalized, together with the two extra classes, all the group was the subject of questionnaire dealing with the second law.

The statistics of the results showed that the volunteers had no difficulties in solving the questionnaire, while many of the rest could answer correctly only to the questions (A1-A4) and statements (B1-B2), for which knowledge gained during traditional course is enough.

Engineering analysis based on both laws of thermodynamics ensures accurate results. Entropy and second law play an important role in energy conversion. Volunteers were aware of the above mentioned, being able to find correct answers also for questions A5 and A6 and for statements B3 and B4.

Comparison of results obtained by the two subgroups of students reveals the need of redesigning the traditional Thermodynamic course, by including the theory supplied during the extra classes in the course. It will be benefic if the redesign of the course will combine first and second laws in the analysis of energy systems and will insist more on the effect of entropy on energy and, additionally, the students will be aware of the increasing role of entropy in other fields.

In this respect should be introduced an assignment during the semester which will be the prove of the efforts done by the student in order to research the use of entropy in analysis developed in different disciplines.

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Address:

- Conf. Dr. Eng. Feiza Memet, Constanta Maritime University, Mircea cel Batrân 104, 900663, Constanta, feizamemet@yahoo.com