Modern teaching instruments for the establishment of the thermodynamic values of real gases in the training of engineer students

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Abstract: In the hereby study, we describe and present analytically several software applications – designed as an effective complex teaching-learning means but attractive and useful friendly at the same time – developed by us for the students – future engineers – in the oil industry. Our preoccupation is directed towards the building-up and adopting of a modern strategy that should favour the students' active and participative learning, as it is well-known the high level of difficulty and abstractness of this scientific domain. What we are trying to achieve by means of this endeavour is to shift the focus from "to know" to "to know how to do".
In this respect, our research study presents the "Real Gases" software, a learning tool used for the calculation of thermodynamic values of gases and gas mixtures, both hydrocarbons and other gases.

Key words: educational software, thermodynamic values, gases, gas mixtures, teaching-learning instruments

1 General context

Potentially one of the most worrying issues nowadays, both at the level of its research and development, and at the level of refining it, is represented by getting acquainted with the use of the process and of the product with a view to developing human personality, to developing some new technological applications, to the social development in general. University centres find themselves at the top of knowledge, trying – moreover – to change and to process knowledge into educational, technological or social instruments.

The technical education in Romania is trying a full approach, by resorting both to the system of the classical, traditional didactic methods and means, and to the learning strategies and techniques which favour the students' understanding and building-up of their own knowledge.

Our study presents the result of the endeavour related to the improvement of the quality of the technical higher education, by resorting to modern, constructivist methods, procedures and instruments which we consider to be alternative or complementary solutions to the classical or current ones that are put into practice.

To be more exact, it is about the design and the use, in the activity with the students, of a software that includes a set of educational programs that facilitate and improve applicative learning.

As a modern teaching-learning instrument, the educational software develops a wide range of electronic materials, with a view to bringing more effectiveness and simplification to the knowledge and education process by means of:

- orientation, recognition, independent search, individual search;
- comparison, differentiation, networking, association, assignment;
- correlation, synthesis, combination, processing;
- structuring, grasping meaning, generalization;
- task analysis;
- the use of cognitive instruments, as operators: lists or packages of implied algorithms, cognitive networks with variants of solution routes etc. (see E. Joita, 2007, 128-129).

We refer to these types of didactic strategies in the context of the engineering education, as it is well known the fact that the software type of educational program implies a planned and organised learning experience and, at the same time, a systematic, sequential and logical presentation of the content, thus allowing the students to assimilate knowledge in their own manner.

Consequently, our target is, in/through the teaching and learning didactic process, that the students should develop mental processes and work abilities, such as: observation, independent study, processing and representation exercise, construction exercise, the capacity of logical systematization, the capacity to summarize and to shape.

Moreover, we achieve, by means of this didactic strategy, a beneficial interaction between educational actions and modern information technology means.

The purpose of the hereby research study is that of bringing a contribution to the improvement of the quality of teaching for the technical education, by developing and using, when working with students, a software that comprises a set of programs which facilitates and increases applicative learning. The analysis perspective is descriptive and based on determination.

2 The Real Gases educational program: didactic tool for the training of engineering students

2.1 Starting premises

The higher engineering education system in Romania, by the tradition of the way in which the teaching and learning activities are performed, has certain vulnerabilities in what the applicative part is concerned, that of putting into action, into practice the theoretical elements which are presented at a high level of abstractness, rigorously and laboriously during courses.

The philosophy of the Romanian education still grants central attention to the verb “to know” and not necessarily to the syntagm “to know how to do”.

As we could see, the specialty literature presents – usually – calculation relations obtained by introducing some simplifying methods, easy to apply, but which often have unacceptable results from the technical point of view.

Starting from this observation with ascertaining value and with the obvious intention of sorting it out, we intend to build up and make available to the students in the technical/engineering domain some application software which should allow the effective achievement/carrying out of the applicative parts incorporated in the education system: projects, homework, laboratory activities etc.

Apart from the necessity of a calculation methodology which requires a high level of precision and attention, another problem that occurs, with a specific tint for the engineering field, consists in the necessity of using – in the specific calculation algorithm – some properties and characteristics of the materials that the user has to access operatively.

Therefore, it is mandatory to organize them under the form of databases, as an operative and effective working instrument.

The application program we developed mainly aims at a target group made up of the students in the Faculty of Petroleum and Gas Engineering within the Oil-Gas University of Ploiesti, Romania but, at the same time, it can be operational for other users who have competencies in the field of oil and gas.

2.2 Analytical presentation

The program package afferent to the Real Gases chapter (thus called) we proposed is destined for the calculation of the processes in which the gases cannot be considered perfect gases.

At the same time, the program allows the calculation of the properties of the real gases and of the real gas mixtures, by using an appropriate system of menus.

The fundamental idea which is at the core of the development of the program refers to the use of the best/ of the most appropriate calculation algorithms for the respective processes, together with a local database in which the properties of the substances that can be used are to be found.

The main characteristics of the real gases that can be calculated with the help of this program are:

- The compressibility factor: it can be calculated by means of two methods, based on the Redlich-Kong and Lee Kesler equations. Apart from the calculated numerical values, the program shows, under the form of a graph, the value of the compressibility factor in the Z-pr or Z-ln (pr) diagram;
- The thermodynamic properties of the real gases in various states: they can be established by using interactive Ts diagrams which allow the numerical display of the properties used, as well as the graphic representation in the T-s diagram of the required state;
- The Epsilon procedure: allows the calculation of the compressibility factor for gas mixtures, as well as the deviation of the enthalpy and of the entropy of the gas as compared to the perfect gas and the fugacity coefficient.

From the design point of view, the interface of the program is user-friendly, developed and conceived in such a way as the user can easily and with a minimum of effort access the desired algorithm [1].

3Operational description of the educative programs. Modalities of use

3.1 The software application: The Z program

The software application called *The Z Program* allows the calculation of the compressibility factor for the real gases, by using the Lee-Kesler equation, including for the phase change area. In order to obtain a high level of precision, the modelling of the phase change area on small portions was preferred, by using original algorithms.

The domain in which the program works is: 0,3 ≤ Tr ≤ 5, 0,01 ≤ pr ≤ 10. The values of the compressibility factor supplied by this program are highly accurate, comparable with the accuracy offered by similar information technology programs.

Figure 1 shows the interface of this program. The most part of the screen is destined to the graphic representation, in (Z, pr) coordinates of the required point. The Tr isotherm is also drawn, on which the required point is found.

The explanation of the areas in the graphic is interactive, by moving the cursor of the mouse on the segment of interest.

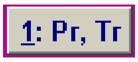
The numerical values corresponding to the required point are shown in two tables which are found on the left side of the screen.

In the first table, there are shown, in order, the values for: the compressibility factor, low pressure, low temperature, enthalpy deviation, entropy deviation and the fugacity coefficient.

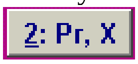
In the second table, there are shown the parameters of the points of intersection of the isotherm of the required point with the curves of saturated liquid and saturated vapours.

These values are available only if the low temperature of the required point is lower than value one.

In order to establish the compressibility factor, one of the three available buttons can be used. They can be accessed directly, using the mouse, by placing the cursor over the image of the desired button, followed by pressing the left button of the mouse or using the keyboard, by typing the figure underlined on the button.



This button allows the setting up of the state for which the compressibility factor is calculated, by defining the low pressure and the low temperature. By means of the functions offered by this button, there can be accessed the states of the real gas in the vapour area, liquid or dense fluid, actually all the states outside the phase change area.



The button allows the calculation of the compressibility factor for the states in the phase change area, including on the curves that represent the saturated vapours or saturated liquid. These states are defined by the low pressure and the vapour title.

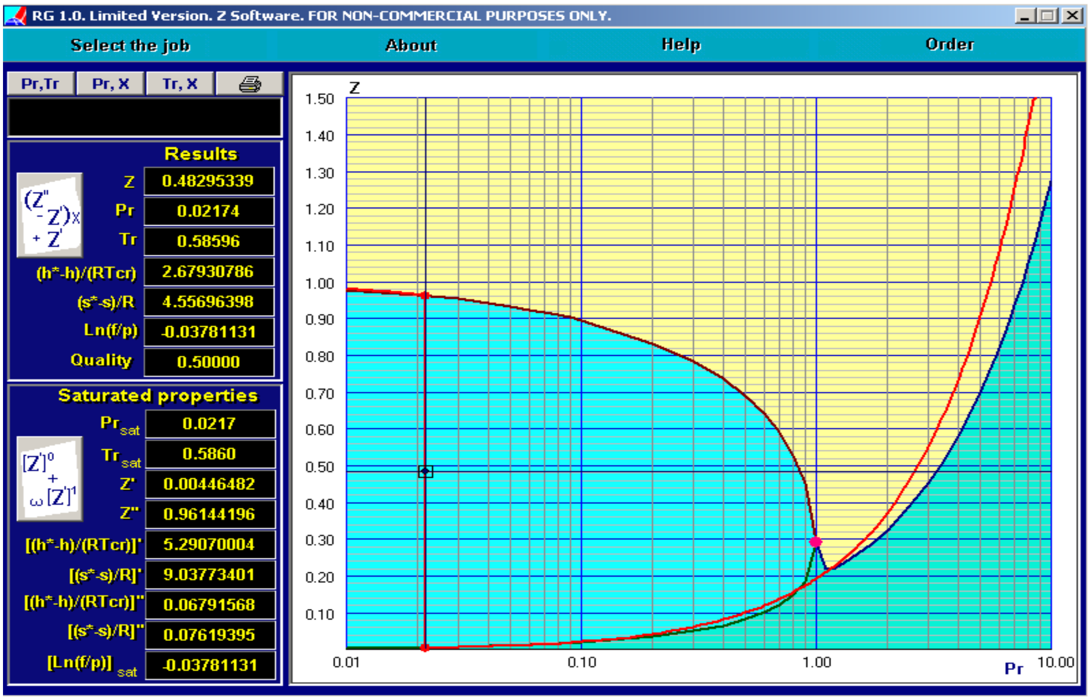
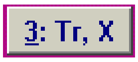


Fig. 1 The graphic interface for the Z program



The button allows the calculation of the compressibility factor for the states in the phase change area, including on the curves that represent the saturated vapours or saturated liquid. These states are defined by the low temperature and the vapour title.

Accessing one of the respective buttons results in displaying a dialogue form in which the initial data are introduced (figure 2).

By means of this form there can be introduced, in two ways, the parameters of the state for which the compressibility factor is calculated. When the form is displayed on the screen, the first data input mode is implicitly chosen.

According to the chosen button, the following are required: the acentric factor, low pressure and the low temperature. If one of the buttons for the phase change area was accessed, the vapour title will be required.

For the situation in which the user does not know the parameters of the gas critical point (critical pressure, critical temperature and the acentric factor), the second mode of data input can be used, by clicking the title of the second panel (figure 2). In this way, the user must introduce only the pressure and the temperature (and, perhaps, the title, according to the chosen button), then, by accessing one of the two databases, called **Hydrocarbons** or **Other Substances**, the desired substance is chosen from the list (figure 3).

By clicking the name of the substance in the list, the program automatically introduces the values of the critical pressure, of the critical temperature and the acentric factor, in the columns destined for them.

Now, the button with the name *Calculate reduced parameters* becomes available, and by using it the reduced parameters are established. If they are within the limits accepted by the program, the confirmation button becomes available, marked OK.

Its access establishes the calculation of the compressibility factor for the defined state, together with all its parameters, as well as the graphic representation of the point that defines the state.

After each calculated state, the *Print* button becomes available. By using it, we print a sheet in which all the parameters referring to the required state are put down, together with the graphic representation of the point [2].

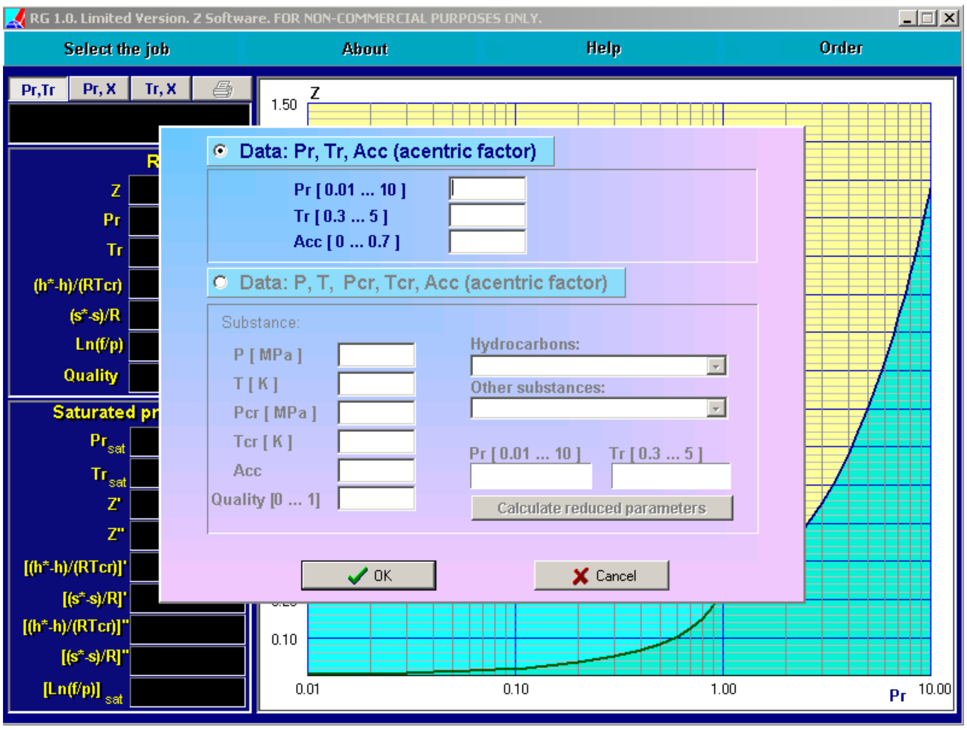


Fig. 2 The dialogue form for data input

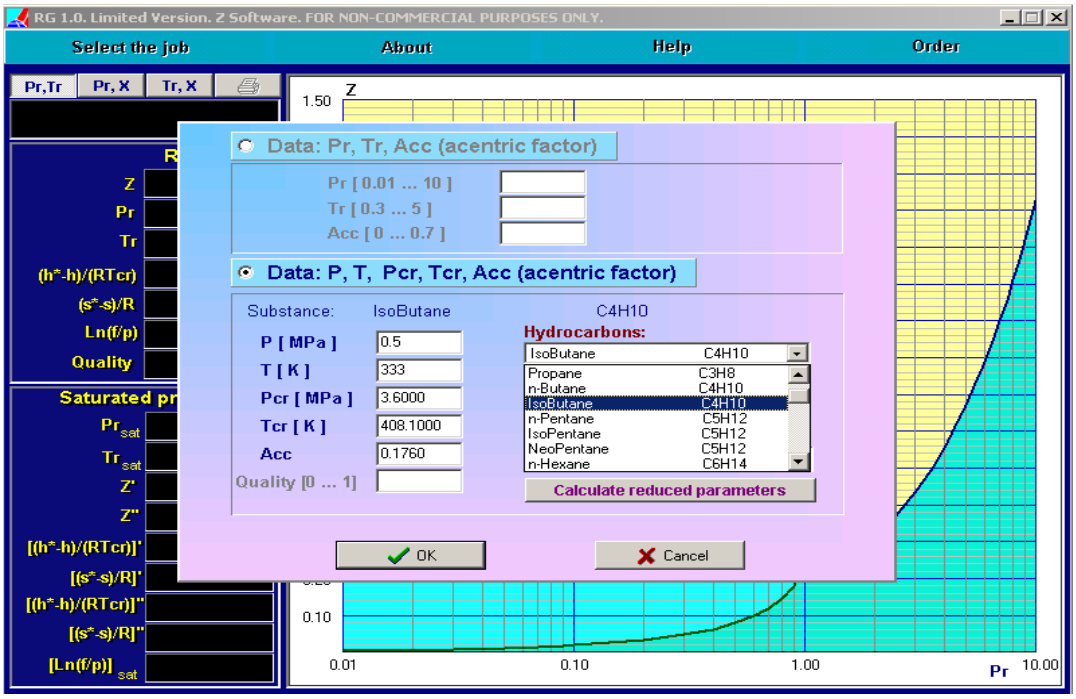


Fig. 3 Accessing the database

3.2 Graphical representation of the results

In the following, there will be shown the results obtained by using the functions offered by the program for each representative area (figures 4, 5, 6).

Analytically, the plot shows a representation of the specific input data, the values calculated as sum between the reference value and the corrected acentric factor, for the compressibility factor Z, enthalpy deviation, entropy deviation along with stint coefficient.

3.3 The TS Diagram Program

By using information technology programs Z and Zrk, there can be obtained values for: the compressibility factor, entropy and enthalpy deviations to the perfect gas state, as well as the fugacity coefficient.

With these sizes there can be calculated, for a thermodynamic system in which there is real gas, the variations of the enthalpy and entropy, which allows the establishment of the performances of the system (technical mechanical work, power) or exchanges of thermal energy (received heat, released heat etc.).

The manual performance of these calculations is laborious, the final value being established, in most cases, by successive tests (as exemplified in the case of the compression or expansion processes).

All these reasons led to the development of an information technology program which can establish directly, at absolute value, the thermodynamic parameters of the real gases. The software application was called the TS Diagram Program because, apart from the fact that it offers the possibility to establish the thermodynamic parameters, it also ensures a graphic representation in T-s coordinates specific to the point that represents the required state.

The curves that are characteristic to the respective gas are calculated first: the curve for the vaporization starting points, the curve for the vaporization ending points, the critical point and the critical isobar. Practically, for each substance, the specific **Ts** diagram is built up, on which the points are subsequently represented.

The thermodynamic parameters calculated by using the TS Diagram program shall be established as follows:

- The specific volume shall be established based on the comprehensibility factor, calculated with the procedures that are specific to the Z program;
- Enthalpy shall be established based on the deviation of enthalpy as to the perfect gas state, calculated with the procedures of the Z program, using a state of reference and formulas (1) and (2).

$$h_2 - h_1 = -\left(h_2^* - h_2\right) + \left(h_2^* - h_1^*\right) + \left(h_1^* - h_1\right) \quad (1)$$

In expression (1), the left member represents the enthalpy variation between the two states, 1 and 2, and the right member contains the following terms:

$(h_2^* - h_2)$ - the isotherm deviation of enthalpy in state 2 as to perfect gas state, due to the pressure variation;

$(h_1^* - h_1)$ - the isotherm deviation of enthalpy in state 1 as to perfect gas state, due to the pressure variation;

$(h_2^* - h_1^*)$ - the isobar variation of the gas enthalpy, considered perfect gas, according to the temperatures of states 1 and 2. This variation can be calculated by the formula (2):

$$h_2^* - h_1^* = c_p (T_2 - T_1) \qquad (2)$$

For the calculation of the enthalpy variation between the two states noted 1 and 2 for a real gas, the scheme in figure 4 shall be used. On this scheme there were pointed out the two points, together with the appropriate isobars.

Moreover, the p* isobar was drawn, which represents a pressure of very low value, on which cohesive forces can be neglected, so as the gas at this pressure can be considered perfect gas.

All the points on the p* isobar are considered states of the perfect gas. There shall be noticed the fact that the p* isobar is fictitious, being used only for calculation purposes.

Due to the fact that enthalpy is a state size, namely an exact total differential, there results that the integral defined between the two states does not depend on the route. Under these circumstances, a convenient route can be chosen.

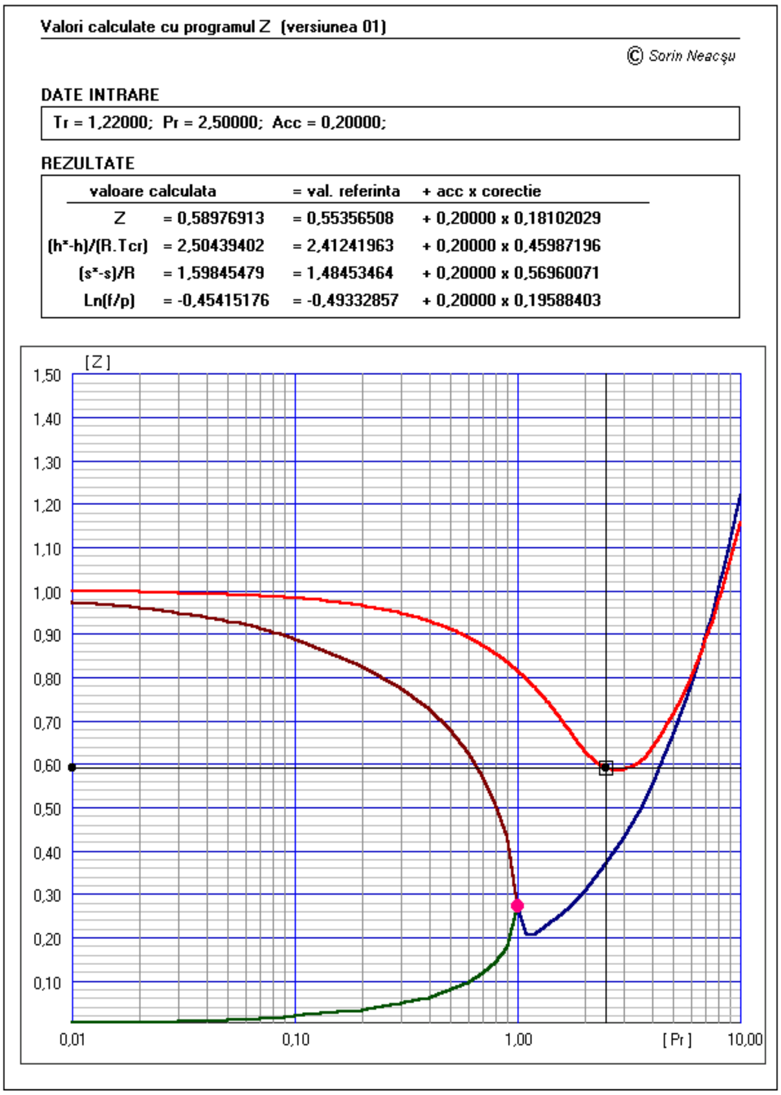


Fig. 4 The state to be found in the dense fluid domain

Valori calculate cu programul Z (versiunea 01)

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DATE INTRARE

Tr = 0,83000; Pr = 0,10000; Acc = 0,12000;

REZULTATE

valoare calculata		= val. referinta	+ acc x corectie
Z	= 0,93334293	= 0,93816961	+ 0,12000 x -0,04022235
(h*-h)/(R.Tcr)	= 0,17470144	= 0,14990260	+ 0,12000 x 0,20665700
(s*-s)/R	= 0,14761977	= 0,12189417	+ 0,12000 x 0,21437996
Ln(f/p)	= -0,06478164	= -0,06022699	+ 0,12000 x -0,03795542

VALORI LA SATURATIE

T sat. = 0,83000000
p sat. = 0,28447916

valoare calculata		= val. referinta	+ acc x corectie
Z lic.sat	0,04503686	= 0,04737134	+ 0,12000 x -0,01945395
(h*-h)/(R.Tcr) lic.sat	4,98922965	= 4,39355293	+ 0,12000 x 4,96397270
(s*-s)/R lic.sat	5,83802483	= 5,22394285	+ 0,12000 x 5,11734984
Z vap.sat	0,78325863	= 0,80164446	+ 0,12000 x -0,15321526
(h*-h)/(R.Tcr) vap.sat	0,57987412	= 0,48821055	+ 0,12000 x 0,76386309
(s*-s)/R vap.sat	0,50424733	= 0,40803997	+ 0,12000 x 0,80172805
Ln(f/p) sat	-0,19416110	= -0,18003569	+ 0,12000 x -0,11771175

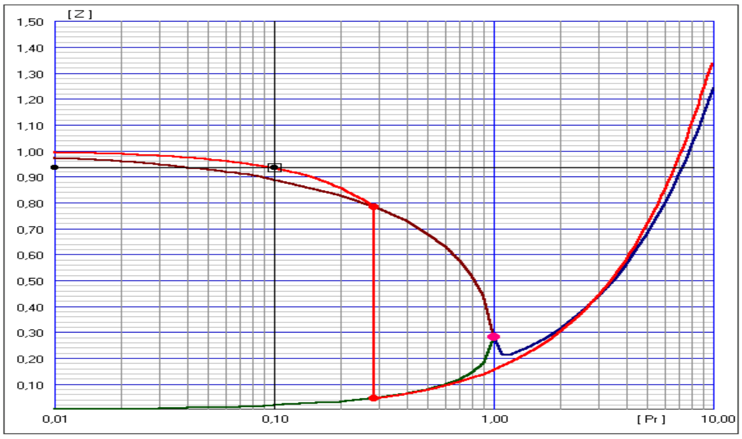

Fig. 5 The state to be found in the vapour domain

Valori calculate cu programul Z (versiunea 01)

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DATE INTRARE

Tr = 0,60000; Pr = 0,30000; Acc = 0,15000;

REZULTATE

valoare calculata		= val. referinta	+ acc x corectie
Z	= 0,05711692	= 0,06115623	+ 0,15000 x -0,02692873
(h*-h)/(R.Tcr)	= 6,21812993	= 5,07642897	+ 0,15000 x 7,61133977
(s*-s)/R	= 6,12248298	= 4,80430210	+ 0,15000 x 8,78787255
Ln(f/p)	= -0,63779766	= -0,53402984	+ 0,15000 x -0,69178548

VALORI LA SATURATIE

T sat. = 0,60000000
p sat. = 0,01654785

valoare calculata		= val. referinta	+ acc x corectie
Z lic.sat	0,00305206	= 0,00326936	+ 0,15000 x -0,00144866
(h*-h)/(R.Tcr) lic.sat	6,29871000	= 5,16360000	+ 0,15000 x 7,56740000
(s*-s)/R lic.sat	10,46364000	= 9,13920000	+ 0,15000 x 8,82960000
Z vap.sat	0,96636970	= 0,97294000	+ 0,15000 x -0,04380200
(h*-h)/(R.Tcr) vap.sat	0,06372930	= 0,04749000	+ 0,15000 x 0,10826200
(s*-s)/R vap.sat	0,07414600	= 0,05252200	+ 0,15000 x 0,14416000
Ln(f/p) sat	-0,03209240	= -0,02663240	+ 0,15000 x -0,03640000

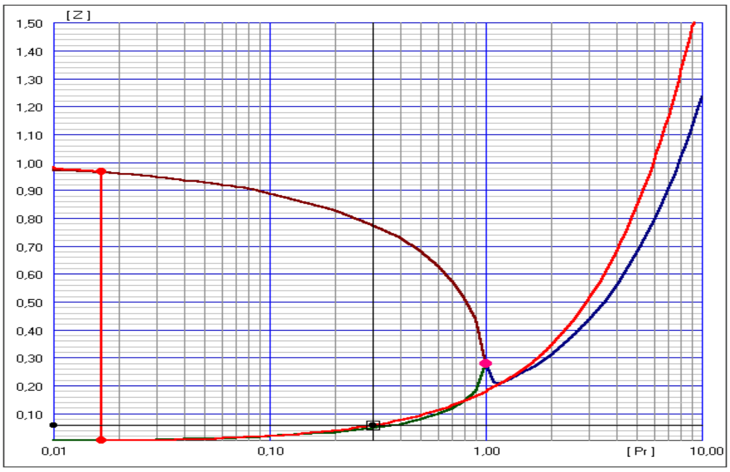


Fig. 6 The state to be found in the liquid domain

Thus, in order to calculate the enthalpy variation, the 1 - 1^* - 2^* - 2 route shall be chosen (figure 7).

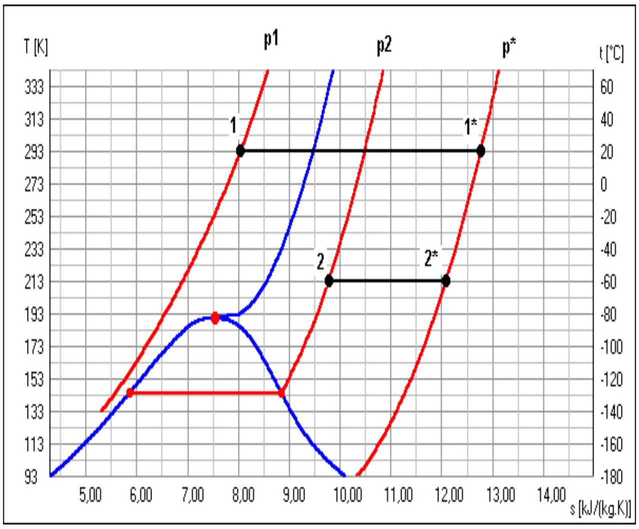


Fig. 7 Usable scheme for the calculation of the enthalpy variation of the real gas

Entropy shall be established based on the deviation of entropy as to the perfect gas state, calculated with the procedures of the Z program, using a state of reference and formulas (3) and (4).

$$s_2 - s_1 = -\left(s^*_{p_2,T_2} - s_2\right) + \left(s^*_{p_2,T_2} - s^*_{p_1,T_1}\right) + \left(s^*_{p_1,T_1} - s_1\right) \quad (3)$$

The significance of the terms in formula (3) is the following:

$\left(s^*_{p_2,T_2} - s_2\right)$ - the isotherm deviation of entropy in state 2 as to perfect gas state, due to the pressure variation.

$\left(s^*_{p_1,T_1} - s_1\right)$ - the isotherm deviation of entropy in state 1 as to perfect gas state, due to the pressure variation.

$\left(s^*_{p_2,T_2} - s^*_{p_1,T_1}\right)$ - the isobar variation of entropy for the gas considered perfect gas, between the temperatures of states 1 and 2. This can be calculated with the help of formula (4):

$$s^*_{p_2,T_2} - s^*_{p_1,T_1} = c_p \mathrm{Ln}\left(\frac{T_2}{T_1}\right) - R\mathrm{Ln}\left(\frac{p_2}{p_1}\right) \quad (4)$$

For the calculation of entropy, the diagram in figure 8 shall be used. In this case, two fictitious states, 1* and 2*, were chosen as being the states of the gas.

The two states were chosen as follows: 1* represents the state in which the real gas would find itself, considered to be perfect gas, at the pressure and temperature of point 1*, and 2* represents the state in which the real gas would find itself, considered to be perfect gas, at the pressure and temperature of point 2*.

Due to the fact that entropy is also a state size, therefore an exact total differential, a convenient route shall be chosen for its integration between state 1 and 2. 1 - 1^* - 2^* - 2.

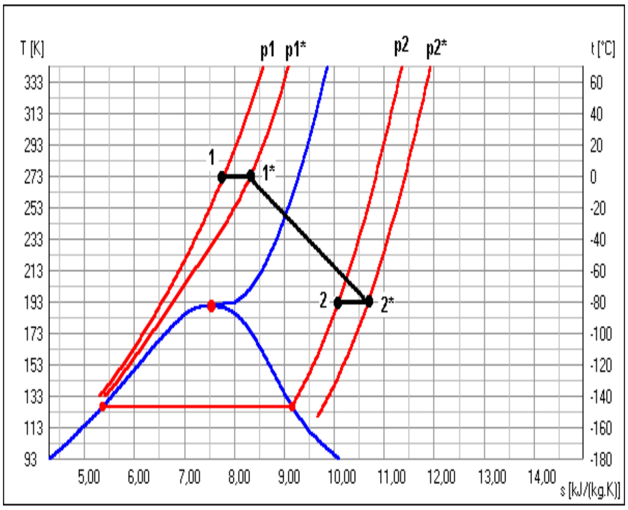
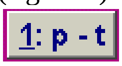


Fig. 8 Usable scheme for the calculation of the entropy variation of the real gas

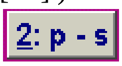
The operation of the TS Diagram program shall be done by means of the graphic interface presented in figure 9.

The first operation that the user must do is to choose the gas he is going to work with. By placing the cursor of the mouse on the Select gas label, at the top left corner of the display and by pressing the left button of the mouse, a menu is displayed, from which the desired gas can be selected.

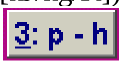
As a result of this choice, the display shows the Ts diagram for the required gas. For example, if there were required data for methane, the display shows the Ts diagram corresponding to this gas (figure 9).



This button allows the definition of a state of methane, by mentioning the pressure (expressed in [MPa]) and temperature (expressed in [°C]).



The button allows the definition of a state of methane, by mentioning the pressure (expressed in [MPa]) and entropy (expressed in [kJ/kg/K]).



This button allows the definition of a state of methane, by mentioning the pressure (expressed in [MPa]) and enthalpy (expressed in [kJ/kg]).

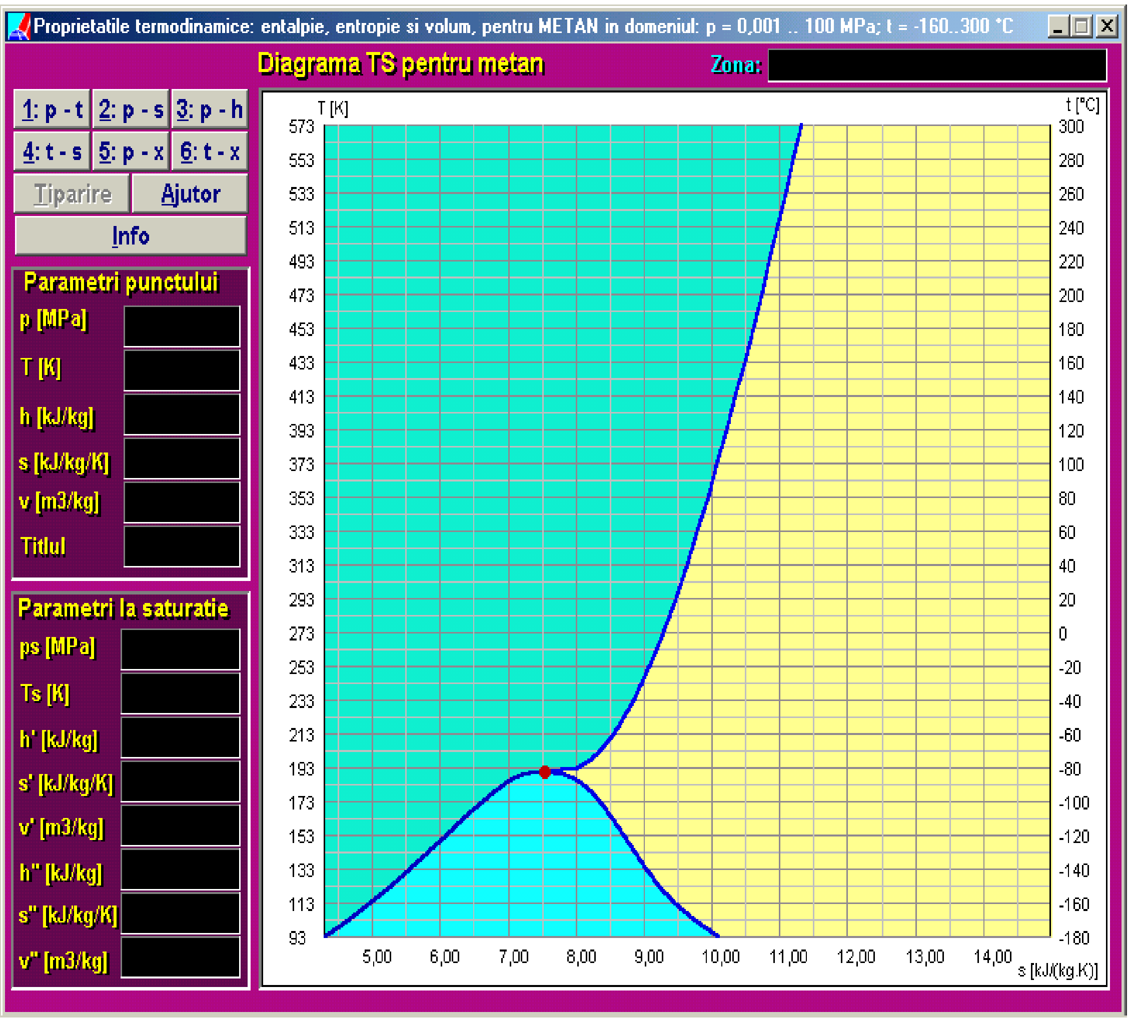
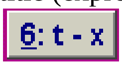


Fig. 9 The graphic interface for the TS program

The button allows the definition of a state of methane, by mentioning the temperature (expressed in [°C]) and entropy (expressed in [kJ/kg/K]).

The button is used only in the liquid-vapours balance area, including on the saturation curves liquid or saturated vapours, the thermodynamic state being stipulated by means of the value of the pressure (expressed in [MPa] and title (expressed in [%]).



This button is used only in the liquid-vapours balance area, including on the saturation curves liquid or saturated vapours, the thermodynamic state being stipulated by means of the value of the temperature (expressed in [ºC] and title (expressed in [%]).

When pressing one of the above-mentioned buttons, a dialogue box appears, in which the parameters are introduced (figure 10).

In the boxes made available by the program, there must be introduced the values of the required sizes, according to the names and units of measurement shown on the display, within the limits mentioned on the labels on the right side of each box.

If the limits are exceeded, the program signals it out and does not allow the passing to the next stage until the conflict is settled.

Further on, it is presented a sheet of results obtained by using the MetanTS program (figure 11).

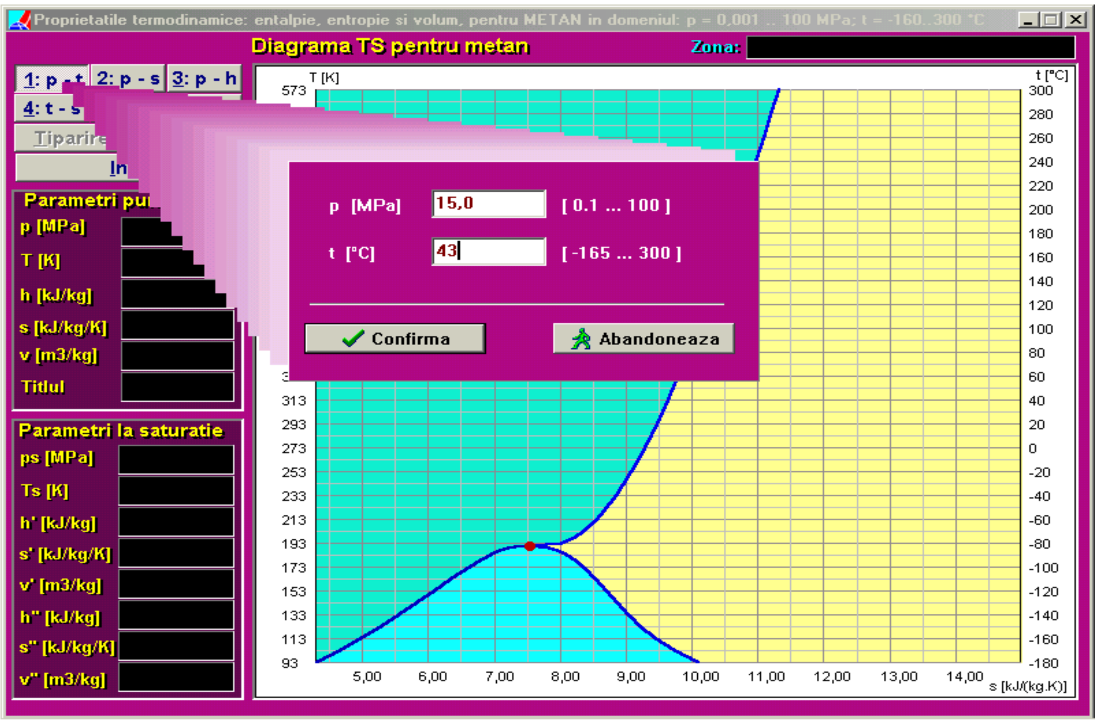
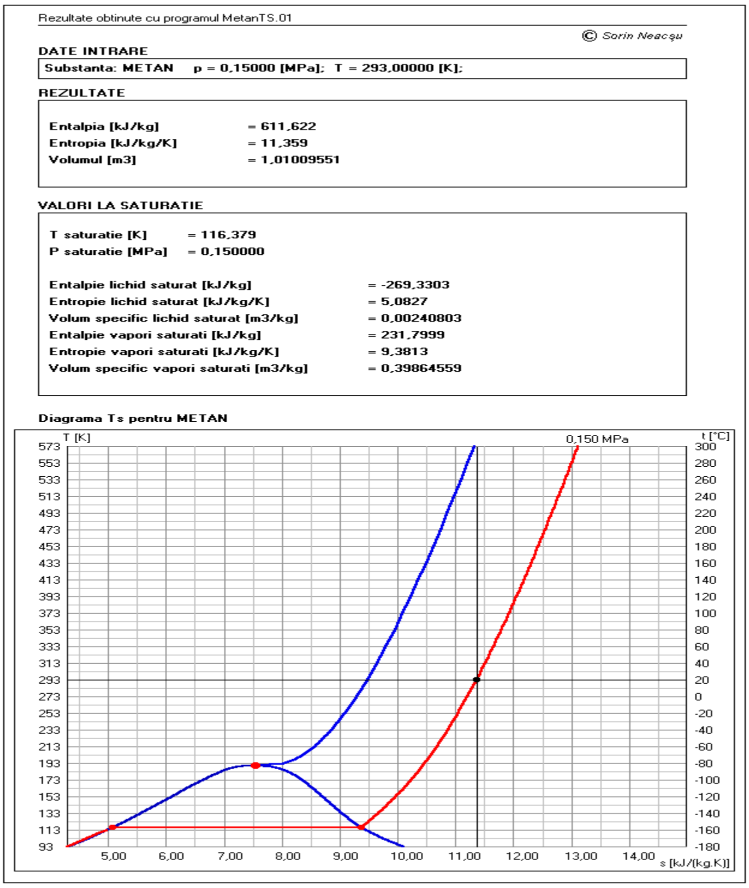


Fig. 10 The dialogue form for data input


Rezultate obtinute cu programul MetanTS.01

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DATE INTRARE

Substanta: METAN p = 0,15000 [MPa]; T = 293,00000 [K];

REZULTATE

Entalpia [kJ/kg] = 611,622
Entropia [kJ/kg/K] = 11,359
Volumul [m3] = 1,01009551

VALORI LA SATURATIE

T saturatie [K] = 116,379
P saturatie [MPa] = 0,150000

Entalpie lichid saturat [kJ/kg] = -269,3303
Entropie lichid saturat [kJ/kg/K] = 5,0827
Volum specific lichid saturat [m3/kg] = 0,00240803
Entalpie vapori saturati [kJ/kg] = 231,7999
Entropie vapori saturati [kJ/kg/K] = 9,3813
Volum specific vapori saturati [m3/kg] = 0,39864559

Diagrama Ts pentru METAN

Fig. 11 The results sheet obtained by using the MetanTS program

4 Methodological Considerations

The software represents an application destined to both daily and reduced frequency education students studying petroleum and mechanical engineering from Oil and Gas University of Ploieşti.

The application has been tested as an experiment with regard to learning and understanding performances improvement for held courses and laboratories.

The working hypothesis was the following: if we use, in the teaching process, the educational software as a modern mean of teaching, then we expect an increase in motivation and performances improvement from the technical area of expertise.

The objective is, beside the one mentioned above, to develop a motivational climate for learning, active presence and participation of the students to both classes and laboratories.

The working sample consisted of 250 students, second year of study, attending the Thermodynamics and Thermal Machineries course. The duration of the observation process was one year and corresponds to the National Learning Plan.

5 Conclusions

We can now present the benefits of using the software described above to both the teaching activity of the professor and the learning activity of the students from the established working sample.

A table, to compare the traditional teaching approach with the proposed model has been realized:

Analysis Criteria	*Traditional Approach*	*New pedagogical approach*
Information transmission	decontextualized	It is placed in action through development
Training Models	Communication systems	Information Systems
Content	The teacher is the only source of information	Diverse sources of information
Teaching	Is based on what the teacher presents	Combines the teacher’s explanations with practical examples/applications
The student	Has a passive role. Works isolated. Does not get involved. Has a spectator role.	Actively participates in the educational activity. Cooperates with his colleagues.
Teaching Strategy	Predominantly informational, cognitive, algorithmic, centred on teaching	Predominantly formative, centred on building practical competences
Methods and Procedures	Expository methods, verbal, based on memory and reproduction	Methods based on action, research and exploration.
Means and Materials	Black board, chalk.	Applicative educational software.
Communication	Predominantly monologue	Open dialogue.
Learning	Slow, abstract – requires memorizing and reproducing efforts	Learning is contextualized, attractive, graphical representations of the proposed software facilitates learning and understanding.
Students motivation	Extrinsic motivation	Intrinsic motivation, participation and active involvement interest for the learning and application process
Time management	Time consuming	Efficient and beneficed time utilization
Evaluation	Written and verbal examination at the end of the year of study	Dynamic formative evaluation, immediate feedback, through correct scroll of the algorithm steps of the software.

References:

[1] Chapman, W.G., Gubbins, K.E. Jackson, G., and Radosz, M., New reference ecuation of state for associating liqids, Ind. Eng. Chem. Res. 29, 1709-1721, 1990.

[2] Karen Schou Pedersen, Peter L. Christensen, Phase Behavior of Petroleum Reservoir Fluids, CRC Press Taylor & Francis Group, London, New York, 2009

[3] Joița. E (coord), Profesorul şi alternativa aconstructivită a instruirii., Craiova, Editura Universitaria, 2007

[4] Michelsen, M.L., State function based flash specifications, Fluid Phase Eqiulibria 158-160, 617-626,1999.

[5] Muchielli, A., (coord.), *Dictionar al metodelor calitative in ştiințele umane şi sociale,* Polirom, 2002.

[6] Neacsu, S., *Logiciels pour les gaz reels*, Collogue Franco – Roumain, COFRET'02 25-27 Avril 2002, Bucarest

[7] Neacsu, S., *Comprimarea şi lichefierea gazelor reale,* Editura Universității din Ploieşti, 2003.

[8] Ioan Neacşu, Emil Stan, Cătălin Popescu, Mihaela Suditu. Managers, Teaching Professionals and the Crisis Impact upon the Education System in Romania- Values, Attitudes, Conduct, http://www.wseas.us/e-library/transactions/education/2010/89-679.pdf, WSEAS TRANSACTIONS ON ADVANCES IN ENGINEERING EDUCATION, ISSN: 1790-1979, Issue 3, Volume 7, March 2010

[9] Redlich, O and Kwong, J. N. S., The thermodynamics of solutions. V. An ecuation of state. Fugacities of gaseous solutions, Chem. Rev. 44, 233-244, 1949

[10] Suditu, M, *Metodologia cercetării educaționale. Teorie şi Aplicații*. Editura Universitatii Petrol-Gaze din Ploiesti, 2008. ISBN 978-973-719-241-7

[11] Van Wylen, G., Sonntag, R., Bornakke, C., *Fundamentals of Classical Thermodynamics,* John Wiley & Sons Inc., New York, 1994.