

Mathematical Description of the Latent Heat of Water Vaporization in Capillary Porous Materials

M. Hadjiski, N. Deliiski, N. Tumbarkova

Key Words: Latent heat; capillary porous materials; water; vaporization; condensation; mathematical description.

Abstract. Some basic characteristics and terms of the latent heat of the materials and especially of the water are considered in this work. The process of vaporization of the liquid fluids has been described and analyzed. Using data from the specialized literature, a mathematical description of the specific latent heat of vaporization of both the free and the bound water in capillary porous materials and products of plant origin has been suggested. The information about the specific latent heat of vaporization of the water in mentioned materials is needed for scientifically based computing of the non-stationary temperature distribution in them during drying and liquefaction processes and also of the duration, energy consumption, and model based control of these processes. The latent heat of condensation of the water and other fluids is widely used when a thermal dimensioning of different equipment is conducted.

1. Introduction

Latent heat is the thermal energy, which is absorbed or released by a substance, body or thermodynamic system during a change in its physical state (phase).

A phase transition of a given substance occurs without a change in its temperature because the kinetic energy of the atoms and molecules then does not change. Latent heat arises from the work required to overcome the forces that hold together atoms or molecules in the material. The energy, released during some phase transitions, comes from the potential energy stored in the bonds between the particles of the substance [10, 13].

The term “latent heat” was introduced around 1762 by the British chemist Joseph Black. It is derived from the Latin *latere* (to lie hidden). Black had used the term in the

context of calorimetry where a heat transfer caused a volume change in a body while its temperature remained constant [16].

Consequently, the latent heat can be considered as a thermal energy in hidden form, which is input (supplied) or extracted to change the aggregate state of a given substance without changing its temperature [9, 12].

It is known that if a given liquid fluid is subjected to heating at a high temperature it begins to boil and vaporize. The energy, which is input during the boiling, is used for breaking of the bonds and for the change of the molecules’ situation in order to form a gas. That energy is stored in the gas as a potential energy and is called latent heat of vaporization [11, 17].

A liquid differs from a gas in that the forces of attraction between the particles are still sufficient to maintain a long-range order that endows the liquid with a degree of cohesion. As the temperature increases, a transition point (the boiling point) is reached where the long-range order becomes unstable relative to the largely independent motions of the particles in the much larger volume occupied by a vapor or gas. This means that additional heat (the latent heat of vaporization) must be added to break the long-range order of the liquid and accomplish the transition to the largely disordered gaseous state.

If the vapor is subjected to cooling, it condenses to a liquid and then the vapor’s latent energy absorbed during the evaporation is released in the surrounding environment or on the cooling surface.

The aim of the present paper is to suggest a mathematical description of the specific latent heat of

vaporization and condensation of both the free and the bound water in capillary porous materials of plant origin using theoretical and experimental data from the specialized literature.

Such a description is needed for use in models of different processes of thermal and hydro-thermal treatment of capillary porous materials, which contain a vaporization of water in the materials.

2. Basic characteristics and terms of the latent heat of materials

Energy is needed to change the aggregate state of a given substance, i.e., to realize a phase transition from its solid to liquid or from liquid to gaseous state. The potential energy, which is stored in forces between atoms and molecules, must be overcome by the kinetic energy of the particles before changing the aggregate state of the substance.

For example, in order to evaporate water it is needed to input energy for overcoming the forces of attraction of its molecules. If the vapour is subjected to cooling and becomes a liquid, then the latent energy absorbed during the evaporation is released in the surrounding space.

On *figure 1* a scheme is shown for the change in the temperature, T , of a liquid during its heating, as a result of which a phase transition from a liquid to gaseous (vapor) state is realized.

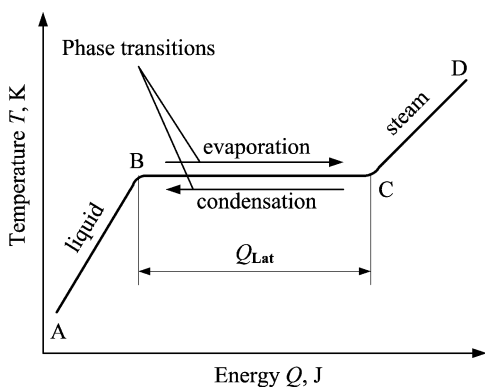


Figure 1. Change in T of a liquid during its phase transition into vapor and from vapor to liquid

During the heating of the liquid, with the help of a thermal energy source Q , it remains entirely in a liquid state from point A until reaching point B. The supplied energy from point A to point B increases the kinetic energy of the liquid, and hence its temperature T .

During further heating of the liquid, it begins to boil and the input energy is spent only on breaking of its intermolecular bonds. This process is ongoing without

increasing of the temperature and goes on until reaching the point C, where the liquid passes completely into a steam state.

The whole amount of energy into the section from point B to point C, Q_{Lat} , is stocked as a potential energy of the steam. The energy Q_{Lat} represents the latent energy of vaporization of the given liquid, which is absorbed in it during its evaporation or is released in the surrounding space during its condensation.

Further addition of heat Q causes an increase of the kinetic energy of the steam's molecules, which leads to an increase of the steam's temperature T in the section from point C to point D.

In SI the latent heat is represented with the help of a parameter "specific heat of phase transition", which is also called as "specific latent heat L ".

This parameter is expressed by the amount of heat Q (in J), which is absorbed or released during the phase transition of a unit of mass m of a given substance (1 mol or 1 kg), i.e.

$$(1) L = \frac{Q}{m}.$$

The dimension of L is in $J \cdot kg^{-1}$ or sometimes in $J \cdot mol^{-1}$ (e.g., in chemistry).

Using Eq. (1), the thermal energy, which is marked with Q_{Lat} on *figure 1*, can be determined in J by the following equation:

$$(2) Q_{Lat} = L_v m,$$

where m is the mass of the liquid, kg; L_v – specific latent heat of vaporization of the given liquid, $J \cdot kg^{-1}$.

In the specialized literature the following kinds of the specific latent heat L are used [12, 16]:

- L_f – specific latent heat of fusion or melting. This is the heat, which is absorbed by a unit of mass solid substance at its melting point in order to transform into a liquid without change of its temperature. A mathematical description of L_f is needed for models of processes with phase transitions of substances from solid to liquid state;

- L_{cr} – specific latent heat of crystallization or solidification. This is the heat, which is released by a unit of mass of liquid substance at its point of crystallization or solidification. The heat L_{cr} is quantitatively equal to the heat of melting L_f . Mathematical description of L_{cr} is used in models of processes with phase transitions of substances from liquid to solid state;

- L_v – specific latent heat of vaporization. According to the explanations above, this is the heat, which is absorbed by a unit of mass of a given material at its point of boiling in order to transform it into a gas at the same temperature. A mathematical description of L_v is needed for models of processes with phase transitions of materials from a liquid to a gaseous state;

- L_c – specific latent heat of condensation or liquefaction. This is the heat, which is released by a unit of mass of a gaseous substance at its point of condensation or liquefaction. The heat L_c is quantitatively equal to L_v . A mathematical description of L_c is used in models of processes with phase transitions of substances from a gaseous to a liquid state;

- L_s – specific latent heat of sublimation. This is the heat, which is absorbed by a unit of mass of solid material when it is transformed directly into a gas. A mathematical description of L_s is used in models of processes with phase transitions of materials from a solid to a gaseous state;

- L_d – specific latent heat of deposition. This is the heat, which is released by a unit of mass of a gaseous substance at its point of solidification without passing through a liquid phase [11]. The heat L_d is quantitatively equal to L_s . A mathematical description of L_d is used in models with phase transitions of substances from a gaseous to a solid state.

In *table 1* the temperature at boiling point t_v (in °C) and the specific heat of evaporation, L_v , of the water and of some metals are given. It can be seen in *table 1* that with an increase of the temperature of the water from 0 to 100 °C its specific heat of vaporization L_v decreases in the range from 2 501 000 to 2 258 000 J·kg⁻¹. The reason for this is the circumstance that the order degree of the molecules of water decreases with an increase of t and for the realization of a phase transition in it less thermal energy is required.

Table 1. t_v and L_v of water and some metals [13]

Name	t_v , °C	L_v , J·kg ⁻¹
Water, 0 °C	100	2 501 000
Water, 25 °C	100	2 441 000
Water, 100 °C	100	2 258 000
Zinc	907	1 890 000
Lead	1 749	866 000
Silver	2 162	2 390 000
Aluminum	2 519	10 900 000
Copper	2 562	4 730 000
Tin	2 602	2 490 000
Gold	2 856	1 645 000
Iron	2 861	6 090 000
Nickel	2 913	6 430 000
Titanium	3 287	8 880 000
Tungsten	5 555	4 390 000

The comparison of the latent heat of vaporization of the water at its boiling point of 100 °C, $L_v = 2\,258\,000$ J·kg⁻¹, with the latent heat of melting of the ice at 0 °C, $L_f = 334\,000$ J·kg⁻¹, [16, 17] shows that L_v is approximately 6.8 larger than L_f . This is due to the significantly bigger difference of the distances between molecules of vapor and liquid compared with the distances between molecules of water and ice. As far as the disorder of the molecules of a given substance is bigger than more potential energy in it during its phase transition is absorbed and stocked.

The very big amount of potential energy L_v , which is stocked during the evaporation of the water, is released as a latent energy L_c during the subsequent condensation of the vapor. This fact makes the condensing steam many times more effective for the heating a fluid in comparison with the hot water in different technical equipments and technologies for thermal and hydro-thermal treatment of the materials.

3. Methodology for calculation of the latent heat of vaporization

As a base of different methods for calculation of the latent heat of vaporization of liquid fluids, in the specialized literature an equation of Clausius-Clapeyron most often is used. It is given as follows [4, 8]:

$$(3) \frac{dP_v}{dT} = \frac{L_v}{T(V_v - V_{lf})},$$

where P_v is the pressure of evaporation of the fluid, Pa; T – absolute temperature, K; L_v – specific latent heat of vaporization, J·mol⁻¹ or J·kg⁻¹; V_v and V_{lf} – volume of the vapor and liquid fluid respectively at temperature T , m³.

The volume of the liquid fluid V_{lf} can be neglected in Eq. (3) due to the circumstance that it is much less than the volume of the resulting steam V_v . Then this equation is simplified and obtained in the following form:

$$(4) \frac{dP_v}{dT} = \frac{L_v}{TV_v}.$$

For steam with low pressure P_v the equation of the state of ideal gases is valid, i.e.

$$(5) V_v = \frac{RT}{P_v},$$

where $R = 8.31441$ J·mol⁻¹·K⁻¹ is the universal gas constant.

After substitution of Eq. (5) in Eq. (4) and simple conversion the following equation for the determination of the molar latent heat of vaporization is obtained:

$$(6) L_v = \frac{dP_v}{dT} \frac{RT^2}{P_v},$$

where

$$(7) \frac{dP_v}{P_v} = \frac{L_v}{R} \frac{dT}{T^2}$$

and consequently

$$(8) \frac{dP_v}{dT} = \frac{L_v P_v}{RT^2}.$$

After neglecting of relatively weak temperature dependence of the latent heat of vaporization L_v of the water in the range from 0 °C to 100 °C (refer to figure 3 below) and integrating of Eq. (8) it is obtained that

$$(9) \ln P_v = -\frac{L_v}{RT} + \text{const.}$$

Hence, if $L_v(T)$ remains practically constant, the representation of $\ln P_v$ as a function of the variable $1/T$ is a straight line, whose negative slope can be used when determining specific latent heat of vaporization L_v .

Examples for the determination of L_v according to the methodology described above during drying of red chillies and shelled corn are given in [4] and [6], respectively. For this purpose, a diagram has been drawn on whose abscissa axis the values of $1/T$ are plotted and along ordinate axis the values of the evaporation pressure P_v in logarithmic scale are situated.

On the chart, the straight lines are drawn and negative slope is equal to the relationship L_v/R . These lines correspond to different constant values of the initial moisture content of the materials subjected to drying. They form a segment on the abscissa axis, whose length is equal to the constant in Eq. (9).

The values of $\ln P_v$ are calculated by multiplying the relative humidity of the drying agent, ϕ , by the water vapor saturation pressure, $P_{v\text{-sat}}$, at a given drying temperature. These values of $\ln P_v$ are situated along the ordinate axis. By multiplying the slope of the straight lines on the diagram $\ln P_v = f(1/T)$ by the universal gas constant R the values of the specific latent heat of vaporization L_v for different initial moisture content of the subjected to drying capillary porous materials are obtained.

The values of ϕ , which are needed for the calculation of $\ln P_v$, are determined (analytically or graphically) using the sorption isotherms of the subjected to drying specific material as a function of the temperature t and equilibrium moisture content, u_{emc} , of that material.

As an example, on figure 2 a diagram for the change in ϕ depending on t and u_{emc} for subjected to drying solid wood materials is shown.

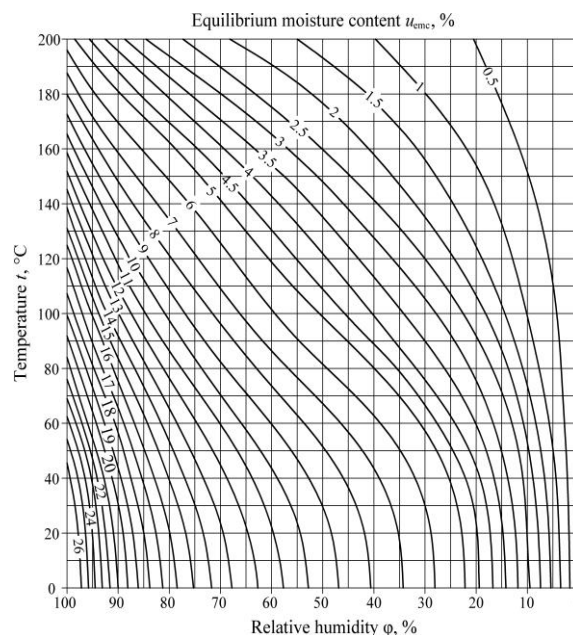


Figure 2. Change in ϕ depending on t and u_{emc} of solid wood [1]

In table 2 the change in water vapor saturation pressure, $P_{v\text{-sat}}$, and in the latent heat of vaporization of the liquid water, $L_{v\text{-sat}}$, depending on the temperature t in the range from 0.01 to 200 °C is presented [10]. The table shows that in the pointed range of t the pressure $P_{v\text{-sat}}$ increases from 0.612 to 1554.9 kPa and the specific latent heat $L_{v\text{-sat}}$ decreases from 2 500 900 to 1 939 700 J·kg⁻¹.

Table 2. Change in $P_{v\text{-sat}}$ and $L_{v\text{-sat}}$ depending on t [10]

$t, ^\circ\text{C}$	$P_{v\text{-sat}}, \text{kPa}$	$L_{v\text{-sat}}, \text{J}\cdot\text{kg}^{-1}$
0.01	0.612	2 500 900
20	2.339	2 453 500
40	7.385	2 406 000
60	19.946	2 357 700
80	47.414	2 308 000
100	101.420	2 256 400
120	198.670	2 202 100
140	361.540	2 144 300
160	618.230	2 082 000
180	1002.800	2 014 200
200	1554.900	1 939 700

4. Mathematical description of L_v of free and bound water in capillary porous materials of plant origin

In models of drying processes of different capillary porous materials as a rule a mathematical description of L_v of both the free and the bound water depending on the influencing factors participates.

According to the numerous results in the specialized literature, the moisture content u of the subjected to drying materials and the temperature t of the drying agent are the most influencing factors on L_v . It was found that with an increase of u the latent heat L_v decreases.

For example, at low temperature drying (below 50 °C) of shelled corn the latent heat L_v decreases almost linearly by 16% when u increases from 8% to 22% [6].

In *table 3* the relationship between the specific latent heat of vaporization L_v of red chillies with moisture content u in the range from 5 to 200% to the water vapor saturation pressure P_{v-sat} at drying temperatures from 25 to 45 °C is shown, which has been derived in [4].

Table 3. Change in the relationship L_v / L_{v-sat} for red chillies depending on u during their drying at $t = 25 - 45$ °C [4]

Moisture content W , %	L_v / L_{v-sat} , -
200	1.0063
150	1.0096
100	1.0174
75	1.0264
50	1.0463
25	1.1102
20	1.1400
15	1.1836
10	1.2488
5	1.3421

The values of L_v in [4] are calculated with the help of Eq. (9) and of the described above methodology for its application.

The values of L_{v-sat} in [4] are calculated according to the following equation:

$$(10) L_{v-sat} = (2502.535259 - 2.38576424t) \times 10^3,$$

which is valid at $0 \text{ °C} \leq t \leq 65 \text{ °C}$, as it approximates with high accuracy the data from *table 2* for L_{v-sat} in the pointed temperature range.

The analysis of the data in *Table 3* shows that a decrease in u of the red chillies causes an increase of the

relationship L_v / L_{v-sat} from 1.0063 to 1.3421. This means that the latent heat of vaporization L_v at $u = 5\%$ is larger approximately by 33% than the latent heat of evaporation of the free liquid water L_{v-sat} .

Especially significant is the increase in L_v when the red chillies contain only bound water. For example, a decrease of u from 25% to 5% causes an increase of the relationship L_v / L_{v-sat} from 1.1102 to 1.3421, i.e., approximately by 21%.

Analogous results have been obtained also when determining of the relationship L_v / L_{v-sat} during evaporation of the available water in different grades of rice, wheat, soya bean, bananas, seeds of pepper, and other capillary porous materials of plant origin [4, 5, 7, 8, 15]. It was discovered that the equilibrium moisture content u_{emc} and the latent heat of water vaporization L_v are similar in different cereals with similar sizes.

The data for L_v / L_{v-sat} given in *table 3* is approximated with high accuracy (correlation 0.999) using the accessible in Internet software package Table Curve 2D [14] by the following equation:

$$(11) \frac{L_v}{L_{v-sat}} = \frac{a + cu^{0.5} + eu}{1 + bu^{0.5} + du + fu^{1.5}},$$

whose coefficients are equal to: $a = 1.3757$, $b = -0.2745$, $c = -0.3231$, $d = 0.0872$, $e = 0.0903$, $f = 7.508 \cdot 10^{-5}$, and u is the initial moisture content of the subjected to drying material, %.

Figure 3 presents the curvilinear dependence $\frac{L_v}{L_{v-sat}} = f(u)$ drawn by Table Curve 2D and also the values of the coefficients in Eq. (11) calculated by the software package.

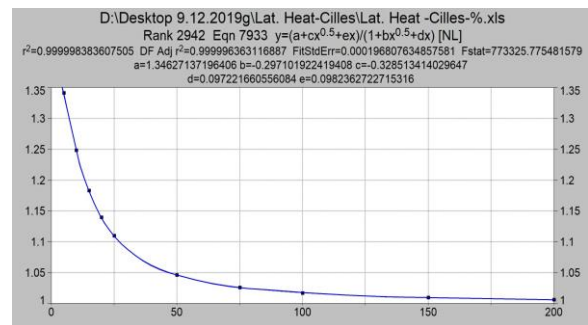


Figure 3. Approximation by Table Curve 2D of the relationship $L_v / L_{v-sat} = f(u)$ for red chillies [4, 14]

After transformation of Eq. (11) it is obtained that the specific latent heat of vaporization L_v can be calculated according to the following equation:

$$(12) L_v = L_{v-sat} \times \frac{1.3757 - 0.3231u^{0.5} + 0.0903u}{1 - 0.2745u^{0.5} + 0.0872u + 7.508 \cdot 10^{-5} u^{1.5}}$$

Eq. (12), together with Eq. (10) can be used as a mathematical description of L_v in models of low temperature (below 65 °C) drying processes of different capillary porous materials and products of plant origin.

In models of drying processes of such products at temperatures in the range 0 °C ≤ t ≤ 200 °C as a mathematical description of the latent heat L_{v-sat} , which participates in Eq. (12), the following equation can be used:

$$(13) L_{v-sat} = \frac{a + ct^{0.5}}{1 + bt^{0.5} + dt} \times 10^6,$$

whose coefficients are equal to: $a = 2.50197$, $b = -0.04131$, $c = -0.10799$, $d = 4.2962 \cdot 10^{-4}$, and L_{v-sat} is the specific latent heat of vaporization of the water (in J·kg⁻¹) at pressure, equal to P_{v-sat} .

Eq. (13) approximates with high accuracy (correlation 0.999) the data given in table 2 for the change in L_{v-sat} of liquid water in the whole range of t from 0.01 to 200 °C.

Figure 4 presents the dependence $L_{v-sat} = f(t)$ drawn by Table Curve 2D and also the values of the coefficients in Eq. (13) calculated by that software package. The dimension of L_{v-sat} is in MJ·kg⁻¹.

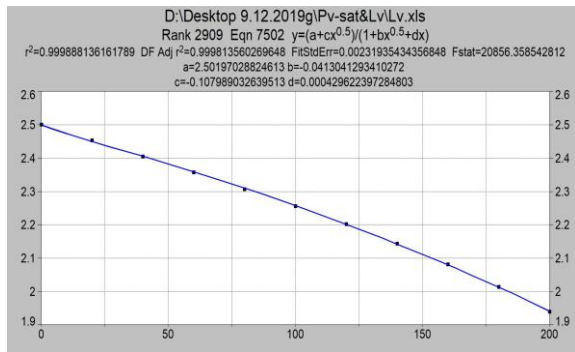


Figure 4. Change in L_{v-sat} of liquid water at P_{v-sat} , depending on t [10, 14]

For application of the methodology for calculation of the latent heat of vaporization of the water described above it is needed to have information for the water vapor saturation pressure, P_{v-sat} at a given drying temperature of the specific capillary porous material.

As a mathematical description of that pressure the following equation can be used:

$$(14) P_{v-sat} = \frac{a + ct^{0.5} + et + gt^{1.5}}{1 + bt^{0.5} + dt + ft^{1.5}} \times 10^3,$$

whose coefficients are equal to: $a = 0.582695$, $b = -0.187985$, $c = 0.181192$, $d = 0.012178$, $e = -0.081696$, $f = -2.69584 \cdot 10^{-4}$, and the pressure P_{v-sat} has a dimension in Pa.

Eq. (14) approximates with high accuracy (correlation 0.999) the data given in table 2 for the change of P_{v-sat} in the whole range of the temperature from 0 to 200 °C.

Figure 5 presents the dependence $P_{v-sat} = f(t)$ drawn by Table Curve 2D and also the values of the calculated coefficients in Eq. (14). The dimension of P_{v-sat} is in kPa.

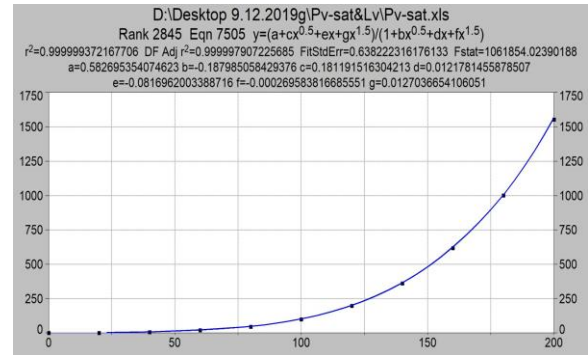


Figure 5. Change in P_{v-sat} of the water depending on t [14]

5. Conclusions

Some basic characteristics and terms of the latent heat of the materials at their different kinds of phase transitions are being considered in this work.

Based on an analysis of data from the specialized literature the most frequent use of the equation of Clausius-Clapeyron for the calculation of the latent heat of vaporization L_v of fluids has been found.

For the solution of that equation aimed at the determination of L_v during drying processes of capillary porous materials, information about the following parameters is needed:

- initial moisture content of subjected to drying materials;
- temperature of the drying agent;
- relative humidity of the drying agent;
- equilibrium moisture content of the materials at the corresponding t and ϕ of the drying agent;
- water vapor saturation pressure at the temperature of the drying agent.

Using the accessible on the Internet software package Table Curve 2D and data from literature sources an

equation for the calculation of L_v of both the free and the bound water in capillary porous materials of plant origin with moisture content from 5 to 200% during their low temperature (below 65 °C) drying has been derived.

With the help of the same software package, equations for the determination of the water vapor saturation pressure P_{v-sat} and of the latent heat of evaporation of the liquid water L_{v-sat} , depending on the temperature in the range from 0 to 200 °C have been obtained. These equations can be applied in mathematical descriptions of L_v of the free and the bound water in that whole temperature range.

The results obtained in the present work can be used for scientifically based determination of the specific latent heat of vaporization L_v and of the energy consumption Q_{Lat} in mathematical models of drying or dehydration processes of capillary porous materials of plant origin, and also in the software of programmable controllers for optimized model based automatic control of such processes [2, 3].

Symbols

L	=	latent heat (J·kg ⁻¹)
m	=	mass (kg or mol)
P	=	pressure (Pa)
Q	=	energy (J or kWh)
R	=	universal gas constant ($R = 8.31441 \text{ J} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}$)
t	=	temperature (°C): $t = T - 273.15$
T	=	temperature (K): $T = t + 273.15$
U	=	moisture content (%)
V	=	volume (m ³)
φ	=	relative humidity (%)

Subscripts

c	=	condensation
cr	=	crystallisation
d	=	deposition
emc	=	equilibrium moisture content
f	=	fusion (melting)
Lat	=	latent
lf	=	liquid fluid
s	=	solidification
sat	=	saturation
v	=	vaporization

References

1. Deliiski, N. Evaluation of Wood Sorption Models and Creation of Precision Diagrams for the Equilibrium Moisture Content. – *Drvna Industrija*, 62, 2011, No. 4, 301–309, <https://doi.org/10.5552/drind.2011.1115>.
2. Hadjiski, M., N. Deliiski. Advanced Control of the Wood Thermal Treatment Processing. – *Cybernetics and Information Technologies*, Bulgarian Academy of Sciences, 16, 2016, No. 2, 179–197, <http://dx.doi.org/10.1515/cait-2016-0029>.
3. Hadjiski, M., N. Deliiski, A. Grancharova. Application of Neural Networks to the Optimization of the Thermal

- Treatment Process of Wood Materials. – *Information Technologies and Control*, Year XV(1), 2017, 2–8.
4. Kaleemullah, S., R. Kailappan. Latent Heat of Vaporization of Moisture from Red Chillies. – *International Journal of Food Properties*, 8, 2005, No. 2, 199–205, <https://doi.org/10.1081/JFP-200060232>.
 5. Lee, J. H., D. C. Kim, O. W. Kim, J. W. Han, W. Kim, H. Kim. Latent Heat of Water Vapor of Rough Rice, Brown Rice, White Rice and Rice Husk. – *Journal of Biosystems Engineering*, 36, 2011, No. 4, 267–272, <https://doi.org/10.5307/JBE.2011.36.4.267>.
 6. Rodriguez-Arias, J. H., C. W. Hall, F. W. Bakker-Arkema. Heat of Vaporisation for Shelled Corn. – *Cereal Chem*, 40, 1963, 676–683, <https://www.aacnet.org/publications/cc/backissues/1963/Documents/CC1963a83.html>.
 7. Silva, P. W., C. M. D. Silva, F. J. G. Gomes. An Empiric Equation for the Latent Heat of Vaporization of Moisture in Bananas during its Isothermal Drying. – *Agricultural Sciences*, 3, 2012, No. 2, 214–220, [doi: 10.4236/as.2012.32025](https://doi.org/10.4236/as.2012.32025).
 8. Silva, W. H., R. S. R. Rodovalho. Adsorption Isotherms and Vaporization Latent Heat of Malagueta Pepper Seeds. – *Jaboticabal*, 44, 2016, No. 1, 5–13, <http://dx.doi.org/10.15361/1984-5529.2016v44n1p5-13>
 9. <https://www.britannica.com/science/latent-heat>
 10. https://www.engineeringtoolbox.com/water-properties-d_1573.html
 11. <http://www.meteo.psu.edu/~jyh10/classes/meteo533-cldphys/classaids/latent-heat-v2.pdf>
 12. http://mrmackenzie.co.uk/wpcontent/uploads/2013/03/Specific_Heat_Lf_and_Lv.pdf
 13. <https://www.physics.info/heat-latent/>
 14. <http://www.sigmaplot.co.uk/products/tablecurve2d/tablecurve2d.php>
 15. <https://www.scribd.com/doc/171167606/Thermal-Properties-of-Foods>
 16. https://en.wikipedia.org/wiki/Latent_heat
 17. https://en.wikipedia.org/wiki/Water/data_page

Manuscript received on 20.12.2018



Academician **Mincho Hadjiski** is a Professor, D.Sc. His scientific interests are in the field of mathematical modeling of technological and power processes, complex hybrid systems incorporation of intelligence in control systems, diagnosis, inference systems, soft sensing, and learning systems. He is an author of more

than 400 scientific papers and 12 books. He was supervisor of 25 Ph.D. students. He was leader of 80 international and national scientific projects and was of more than 60 IPC and NOC of international conferences. Academician Mincho Hadjiski is Editor-in-chief of the journal “Automation and Information”.

Contacts:
Institute of Information and Communication Technologies
Bulgarian Academy of Sciences
Acad. G. Bonchev Str., bl. 2
1113 Sofia, Bulgaria
e-mail: hadjiski@uctm.edu



Prof. Nencho Deliiski received his Ph.D. Degree in 1977 and Doctor of Technical Sciences Degree in 2003. Since 1971 he has been an Assistant, since 1984 – an Associate Professor, and since 2005 – a Professor in the Automation of Woodworking Processes, University of Forestry – Sofia. His research interests are

in the area of mathematical modeling and automation of the heat- and mass-transfer processes in the woodworking and furniture industry. He has more than 450 scientific publications about modeling, improvement, optimization, and automation of the technologies for thermal and hydro-thermal treatment of wood and other materials, and also in this field, he has developed more than 70 systems for automatic control, machines and installations in 22 factories around the country and abroad.

Contacts:

*Department of Woodworking Machines
University of Forestry – Sofia
10 St. Kliment Ohridski Blvd.
1797 Sofia, Bulgaria
e-mail: deliiski@netbg.com*



Eng. Natalia Tumbarkova received her B.Sc. Degree in 2008 and M.Sc. Degree in Mechanical Technology of Wood in 2013 from the University of Forestry in Bulgaria. In June 2019 she received a Ph.D. Degree in the Specialty: Technology, Mechanization and Automation of the Woodworking and Furniture Industry.

She started to participate in scientific conferences and to publish works since 2009 while she was still a student. Her current research interests are in the field of modeling and computation of the non-stationary temperature distribution and energy consumption in wood materials during their freezing and other kinds of thermal treatment.