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Analysis of the evaporation coefficient and the condensation coefficient of water

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Abstract

The evaporation and condensation coefficients of water are extensively analyzed considering also data hitherto not taken into account. From the performed evaluation, a decline of both coefficients with increasing temperature and pressure is derived. For water, the condensation coefficients is generally higher than the evaporation coefficient. Evaporation and condensation coefficients exceed 0.1 for dynamically renewing water surfaces, while the analysis reveals coefficients below 0.1 for stagnant surfaces. The influence of impurities and surface active substances, as well as the effect of the dynamic surface tension is discussed. © 2000 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Despite intensive research, many questions of evaporation and condensation have remained unsolved due to numerous interdependent parameters and the complexity of the corresponding physical mechanisms. The evaporation coefficient $\mathscr{K}_\mathrm{E}$ and the condensation coefficient $\mathscr{K}_\mathrm{C}$ are used to calculate the net mass flux at a plane phase boundary from kinetic theory:

$$\dot{m}^*_\mathrm{net} = \frac{2}{2-\mathscr{K}_\mathrm{C}} \cdot \left(\frac{M}{2\pi\mathscr{R}}\right)^{1/2} \cdot \left\{\mathscr{K}_\mathrm{C} \cdot \frac{p_\mathrm{v}}{T_\mathrm{v}^{1/2}} - \mathscr{K}_\mathrm{E} \cdot \frac{p_\mathrm{l}}{T_\mathrm{l}^{1/2}}\right\} \tag{1}$$

Eq. (1) is known as Hertz–Knudsen–Schrage Equation [85], or Kucherov–Rikenglaz-Equation [49], respectively. For a curved interface, an analogous equation has been derived [60]. A more complex kinetic evaporation and condensation equation taking into account the velocity distribution of the reflected molecules is given by Ytrehus [103]. An overview on interphase mass transfer is given by Rose [81].

In many publications, the evaporation coefficient is not distinguished from the condensation coefficient, both terms are rather used synonymously. Often the simplification

$$\mathscr{K}_\mathrm{E} = \mathscr{K}_\mathrm{C} = \mathscr{K} \tag{2}$$

is introduced into Eq. (1).

The mechanisms involved in condensation and evaporation at an interface are sketched from a molecular view point in Fig. 1. Impinging molecules from the vapour phase can be reflected back into the vapour or can be absorbed by the liquid. Furthermore, some kind of replacement is possible,

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Nomenclature

$\mathscr{K}_\mathrm{C}$	condensation coefficient
$\mathscr{K}_\mathrm{E}$	evaporation coefficient
$\dot{m}^*_\mathrm{net}$	net mass flow rate per unit area (kg $\mathrm{s}^{-1}\mathrm{m}^{-2}$)
M	mass per mole (kg mol^{-1})
p	pressure (N m^{-2})
$\mathscr{R}$	universal gas constant (J mol^{-1} K^{-1})
T	temperature (K)
ϑ	temperature (°C)
v_v	specific vapour volume (m^3 kg^{-1})
Subscripts	
l	liquid
v	vapour

with vapour molecules replacing the same number of liquid molecules in the interface. The mechanisms are analogous for evaporating molecules, as depicted in the lower half of Fig. 1.

For an interface in equilibrium, the net mass flow rate is zero, as the number of evaporating molecules equals the number of condensing molecules. Therefore, Eq. (2) is valid especially for the state of equilibrium. As the interface is usually in a state of non-equilibrium, the identity of the condensation and evaporation coefficient cannot generally be assumed. Moreover, there is no physical reason for Eq. (2), as capture and emission of molecules at an interface depend on different physical mechanisms [42,63]. Picker [74] confirmed the validity of Eq. (2) from growth and condensation experiments of R11 vapour bubbles. However, this finding cannot be generalized for all substances.

To correlate experimental data of evaporation rates with theoretical predictions, Knudsen [43] defined the evaporation coefficient as:

$$\mathscr{K}_\mathrm{E} = \frac{\text{number of molecules transferred to the vapour phase}}{\text{number of molecules emitted from the liquid phase}} \tag{3}$$

$\mathscr{K}_\mathrm{E} < 1$ implies an incomplete evaporation with some of the molecules emitted from the liquid not remaining

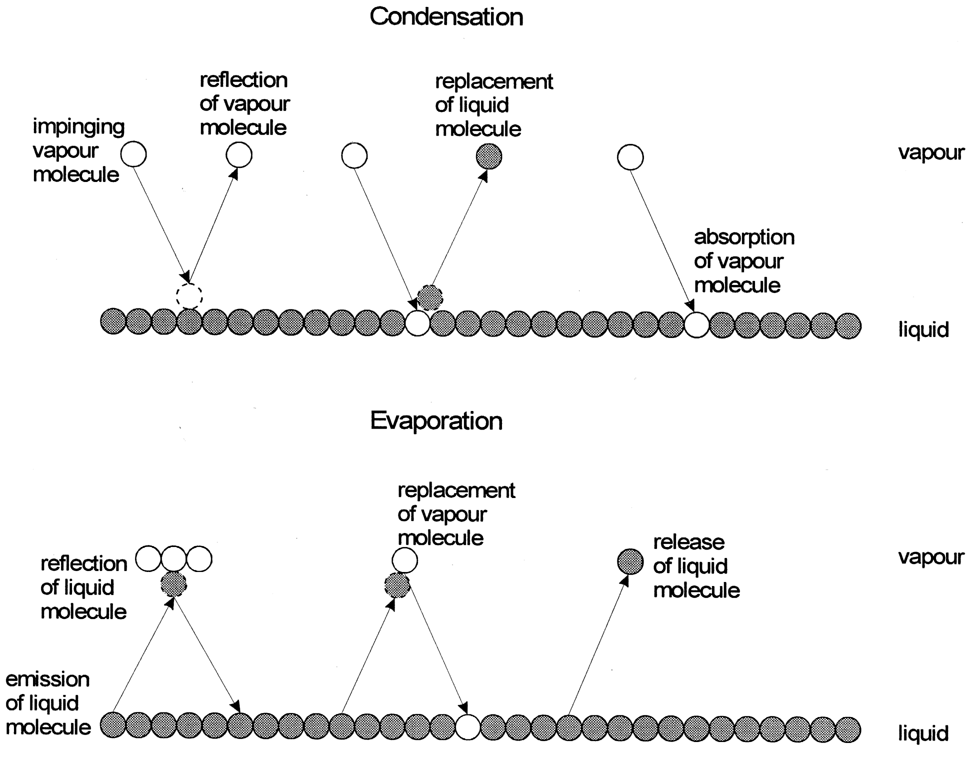

Fig. 1. Molecular mechanisms of condensation and evaporation at a liquid–vapour interface.

in the vapour phase, but returning to the liquid again. $\mathscr{K}_{\mathrm{E}} = 1$ represents a perfect evaporation with all molecules being emitted from the liquid remaining in the vapour phase.

In analogy, Prüger [76] defined the condensation coefficient as:

$$\mathscr{K}_{\mathrm{C}} = \frac{\text{number of molecules absorbed by the liquid phase}}{\text{number of molecules impinging on the liquid phase}} \qquad (4)$$

$\mathscr{K}_{\mathrm{C}} < 1$ denotes an incomplete condensation, i.e. not all vapour molecules striking the interface are absorbed by the liquid, while $\mathscr{K}_{\mathrm{C}} = 1$ represents a complete condensation.

Assuming an ideal gas and neglecting interactions between individual molecules in kinetic theory, the definitions of the evaporation and the condensation coefficients do not include real gas effects, as well. The experimental evaluation of phase change coefficients therefore rather reflects the ratio of measured coefficients to theoretical values predicted by kinetic theory. Thus, the coefficients defined in Eqs. (3) and (4) can also be understood as the adaptation of experimental data to simplified theoretical predictions taking into account real gas effects and peculiarities of the method of measurement employed.

Generally, evaporation and condensation coefficients can be obtained theoretically from molecular dynamical calculations or empirically from evaporation or condensation experiments. Due to its technical importance and the availability of numerous data, the phase change coefficients of water are chosen in the following.

2. Theoretical predictions of phase change coefficients

From molecular data, the evaporation and the condensation coefficients of a substance can be derived by means of statistical mechanics and theoretical physics. For non-polar substances, such as CCl_4, good agreement between measured and theoretical values is obtained, whereas for water deviations of nearly two decades are observed (Fig. 2). According to some models [23,44], the condensation coefficient of water increases with increasing pressure contrary to experimental data, as shown in the following section.

Several authors [17,23,65,102] derive evaporation and condensation coefficients from the free angle ratio of the water molecule. Danon [15] calculates the evap-

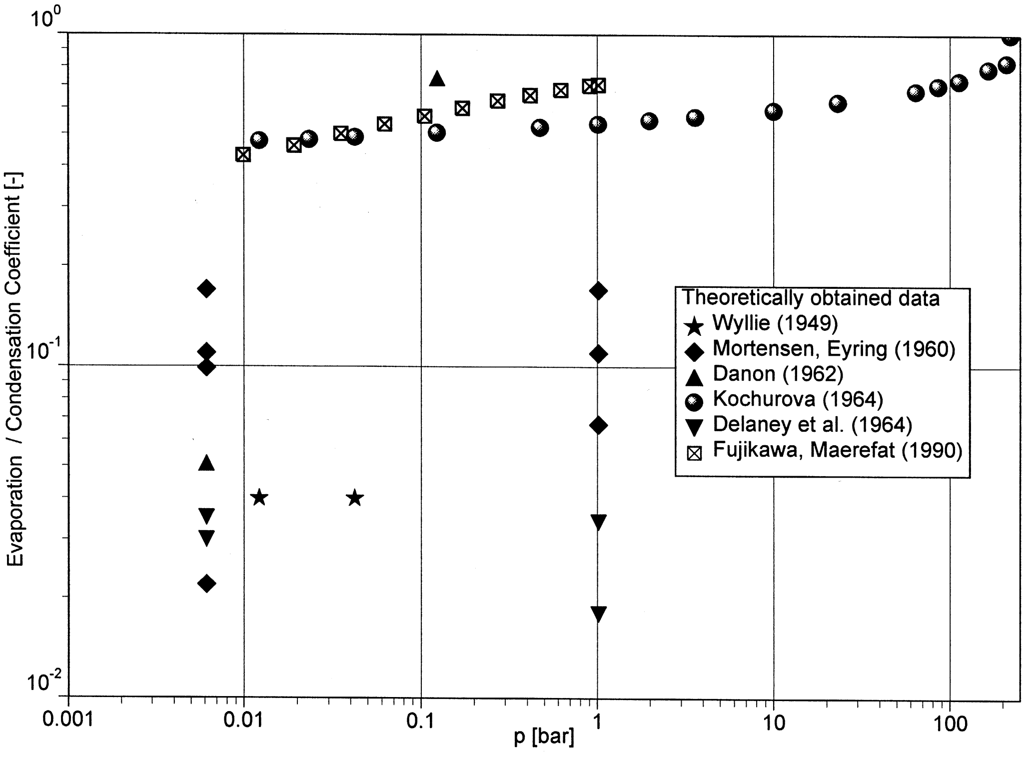

Fig. 2. Theoretically predicted evaporation and condensation coefficients of water.

oration coefficient from the internal evaporation energy of a molecule, while Kochurova [44] uses the hole potential. Matsumoto et al. [61] determine condensation coefficients from molecular dynamics computer simulations.

3. Analysis of experimental data

Evaporation and condensation are not only important in technical equipment, but also in other fields. For example, the formation and dissolution of clouds is decisive for weather forecasting. However, the data provided by geophysics and meteorology are usually not considered in the reviews of evaporation and condensation coefficients. For water, numerous experimental values of the evaporation coefficient [2–5,7,8,11–13,16,17,20,22,27,28,32–35,41,45,47,53–56,62,67,68,76–80,83,90,94] and the condensation coefficient [9,10,14, 21,23–27,29,30,38,39,54–56,59,64,66,69–71,83,86,90–92, 95–97,99,101] are available. Their determination is quite difficult, as the temperature at the interface, which jumps within a few molecule layers, cannot directly be measured. The calculation or extrapolation of the interface temperature from a known bulk temperature of the liquid or vapour is usually associated with errors.

Unlike in this article, some of the works analyzed do not strictly distinct between evaporation coefficient and condensation coefficient (Figs. 3 and 4). Rectangles with corners and straight lines with end points depict regions with no distinct data points available. Like the theoretically calculated coefficients above (Fig. 2), the experimental data scatter over several decades. A unique determination of evaporation and condensation coefficients as a typical property of water dependent on temperature and pressure is not possible. Thus, a categorization of the experimentally determined coefficients into two groups is suggested:

$$0.1 \le \mathcal{K}_{\mathrm{E(C)}} < 1.0 \text{ (group I)} \quad \text{and}$$
$$\mathcal{K}_{\mathrm{E(C)}} < 0.1 \text{ (group II)} \qquad (5)$$

Most of the data of the evaporation coefficient can be categorized into group II (Fig. 3), while most of the condensation coefficients fall into group I (Fig. 4).

The performed analysis reveals the condensation coefficient of water to be higher than the evaporation coefficient. This is confirmed by Rubel and Gentry [83] for water ($\mathcal{K}_\mathrm{C} \approx 1.2 \cdot \mathcal{K}_\mathrm{E}$) and by microgravity experiments for growth and condensation of vapour bubbles in R11 [87].

The experimental methods and setups for measuring the phase change coefficients greatly differ. An over-

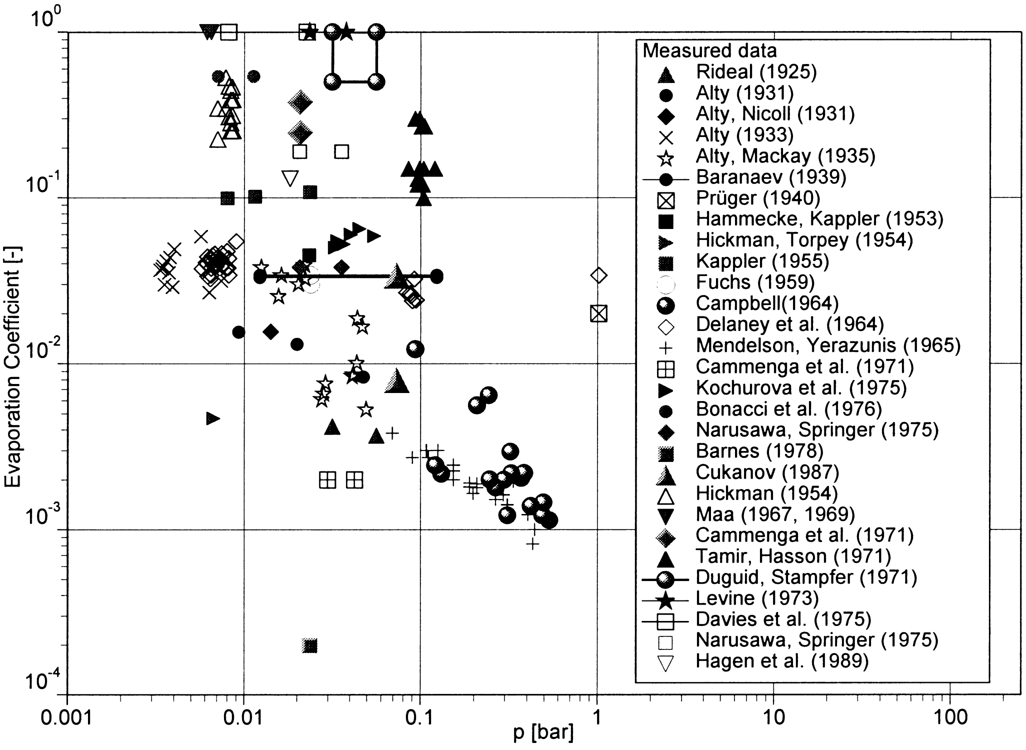

Fig. 3. Evaporation coefficient of water as a function of pressure.

view is given, among others, in [34,36,42,73,75] and concisely in the Tables 1 and 2 below.

In the first evaporation experiments [2,3,80] from a stagnant water surface in a glass vessel into vacuum, evaporation coefficients ranging from 0.004 to 0.015 were deduced. Objections against these low values mainly base on the measurement of surface temperatures with thermocouples and the cooling of the interface by evaporation.

However, the evaporation coefficient of CCl_4 was determined very exactly near unity with the same apparatus [2,3]. Thus, the substance itself seems to have an influence, too. In subsequent experiments Alty [4,5] determined the surface temperature from the surface tension of an evaporating water drop and found evaporating coefficients an order of magnitude higher, between 0.01 and 0.06.

Tschudin [93] attributed the low evaporation coefficient to the high dipole moment of the water molecule. The low evaporation coefficient of polar liquids is usually explained by the orientated liquid surface and the adsorbed gas layer due to the high dipole moment [88,102].

The grouping according to Eq. (5) also applies for the experimental methods. Experiments with a stagnant, quasi-static interface ($\mathscr{K}_{E(C)} < 0.1$) and experiments with a continuously renewing, dynamical interface ($\mathscr{K}_{E(C)} \geq 0.1$) can be distinguished. The meniscus in a glass vessel can be regarded as a quasi-static surface, while a rapidly moving water jet with its short contact time to the surroundings of a jet tensimeter [32,34,35,38,39,54–56] is continuously renewing.

The contamination of a quasi-static water surface significantly impedes evaporation, as the impurities accumulate along the interface and are not carried away. Due to the high dipole moment, water surfaces are very sensitive to contamination. This explains the consistency of the evaporation coefficient with theoretical values for non-polar substances, such as CCl_4 [2,3]. Contrary to stagnant surfaces, renewing surfaces are less sensitive due to their short exposure time. The greater impediment of surface contamination for evaporation explains the generally higher values of the condensation coefficient compared to the evaporation coefficient. The condensation coefficients of group II were mainly gained from droplet growth experiments on atmospheric nuclei or NaCl aerosols in cloud chambers, where the accumulation of contaminants along the interface cannot be excluded. In experiments with film condensation (group I) mainly higher condensation coefficients are reported due to the movement of the film surface.

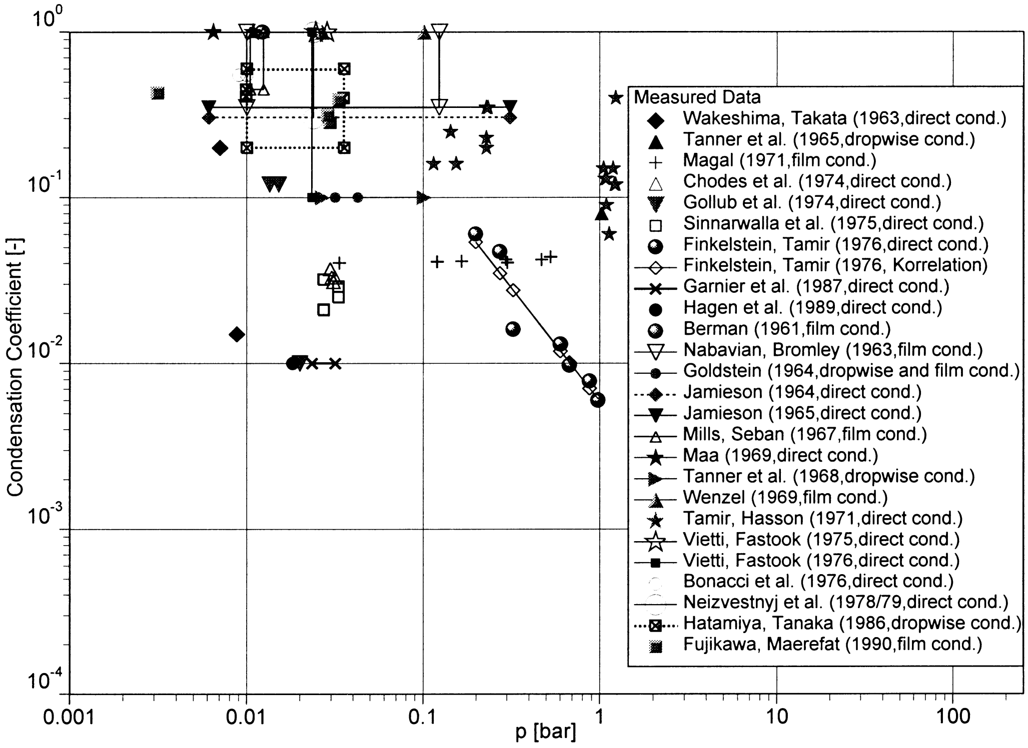

Fig. 4. Condensation coefficient of water as a function of pressure.

Table 1
Evaporation coefficients on quasi-static and dynamically renewing surfaces

Year	Author(s)	$\mathscr{K}_{\mathrm{E}}$	ϑ (°C)	Method
			Quasi-static surfaces	
1925	Rideal [80]	0.0037–0.0042	25–30	Evaporation from a U-tube in a thermal bath into vacuum, measurement of the bath temperature
1931	Alty [2]	0.0083–0.0155	5.9–32	Evaporation from a thermostated glass vessel into vacuum, measurement of surface temperature with thermocouple
	Alty and Nicoll [3]	0.0156	12.1	
1933	Alty [4]	0.0289–0.0584	−7.5–25	Evaporation from a drop formed at the end of a glass capillary into vacuum, calculation of the surface temperature from the surface tension of the drop
1935	Alty and Mackay [5]	0.0061–0.0392	10.3–32.6	Evaporation from a drop formed at the end of a glass capillary into vacuum, calculation of the surface temperature from the surface tension of the drop
1939	Baranaev [7]	0.033−0.034	10–50	Evaporation from a glass tube into vacuum, meniscus touches thermocouple
1940	Prüger [76]	0.02	100	Heating of water above saturation temperature, measurement of superheat with a very fine thermocouple
1953	Hammecke and Kappler [28]	0.045	20	Evaporation from a plane water surface, determination of surface temperature from thermal radiation by pyrometry
1954	Hickman and Torpey [33]	0.0047	1.2	Evaporation from a stagnant water surface into vacuum, no details about temperature measurement
1955	Kappler [41]	0.0992–0.1015	3.8–20.2	Evaporation from a glass vessel into vacuum, determination of surface temperature from thermal radiation by pyrometry
1959	Fuchs [22]	0.03–0.034	20	No details
1964	Campbell [13]	0.0014–0.0122	44.6–83.0	Evaporation from a flat plate, no details about temperature measurement
1964	Delaney et al. [17]	0.0336–0.0545	−0.8–4.1	Evaporation from a copper-embedded glass vessel into vacuum, measurement of the rise in pressure due to evaporation, measurement of the copper block temperature with a thermocouple
1965	Mendelson and Yerazunis [62]	0.0008–0.0038	38.9–78.3	Evaporation from the stagnation point of a cylinder in air flow, measurement of surface temperature with a thermocouple
1971	Cammenga et al. [12]	0.002	24–30	Evaporation from an extended stagnant surface, measurement of fluid temperature with a thermocouple
1975	Kochurova et al. [45]	0.050–0.065	25.5–34.5	Evaporation from a glass tube into vacuum, measurement of surface temperature with a thermocouple
1975	Narusawa and Springer [67,68]	0.038	18–27	Evaporation from a stagnant water surface into vacuum, determination of surface temperature from thermal radiation of the surface
1976	Bonacci et al. [10]	0.065–0.665 (avg. 0.54)	2.1–8.7	Evaporation from a copper-embedded glass vessel into vacuum, measurement of the rise in pressure due to evaporation, measurement of the copper block temperature with a thermocouple
1978	Barnes [8]	0.0002	25	Extrapolation of evaporation data for a water surface covered with surface active substances, no details about temperature measurement
1987	Čukanov [94]	0.008–0.034	39.8	No details

			Dynamically renewing surfaces	
1954	Hickman [32]	0.254–0.532	5.9–7.3	Evaporation into vacuum from a falling water jet (jet stream tensimeter), measurement of jet bulk temperature with a thermocouple
1967	Maa [54]	1	0.05	Evaporation into vacuum from a falling water jet (jet stream tensimeter), calculation of the surface temperature from the jet bulk temperature
1969	Maa [55]	1	0.8	Evaporation into vacuum from a falling water jet (jet stream tensimeter) calculation of the surface temperature from the jet bulk temperature
1971	Cammenga et al. [12]	0.248–0.380	18	Evaporation from a narrow copper capillary or copper block, measurement of the rise in pressure in a closed vessel, no details about temperature measurement
1971	Tamir and Hasson [90]	0.10–0.30	42–50	Evaporation from a thin flowing water film, interferometric measurement of the change in film thickness, no details about temperature measurement
1971	Duguid and Stampfer [20]	0.5–1	25, 30, 35	Evaporation from freely falling micrometric droplets, determination of steam temperature from thermostat temperature
1973	Levine [53]	1	20–28	Evaporation of sessile droplet into a saturated steam atmosphere, no details about temperature measurement
1975	Davies et al. [16]	1	4–19.5	Evaporation into vacuum from a falling water jet (jet stream tensimeter), calculation of the surface temperature from the jet bulk temperature
1975	Narusawa and Springer [67],[68]	0.19	18–27	Evaporation from a flowing water film into vacuum, determination of surface temperature from thermal radiation of the surface
1989	Hagen et al. [27]	0.13	16	Evaporation of a droplet in a cloud chamber, measurement of droplet radius by light scattering, no details about temperature measurement

Table 2
Condensation coefficients on quasi-static and dynamically renewing surfaces

Year	Author(s)	$\mathscr{K}_C$	ϑ (°C)	Method
				Quasi-static surfaces
1963	Wakeshima and Takata [99]	0.015–0.020	−16.1–5.1	Growth of droplets in superheated vapour, measurement of droplet radius by light scattering, no details about temperature measurement
1965	Tanner et al. [91]	> 0.08	100	Dropwise condensation on a vertical copper surface, measurement of block temperature with thermocouples
1971	Magal [59]	0.040–0.044	25.9–82.8	Film condensation, no details
1974	Chodes et al. [26]	0.031–0.037	23.9–24.9	Direct contact condensation on atmospheric nuclei in a cloud chamber with horizontal flow, no details about temperature measurement
1974	Gollub et al. [86]	0.010–0.012	11.4–17.5	Direct contact condensation on atmospheric nuclei in a cloud chamber with vertical flow, measurement of droplet radius by light scattering, no details about temperature measurement
1975	Sinnarwalla et al. [86]	0.021–0.032	22.5–25.7	Direct contact condensation on atmospheric nuclei in a cloud chamber with vertical flow, measurement of droplet radius by light scattering, no details about temperature measurement
1976	Finkelstein and Tamir [21]	0.006–0.060	60–99	Direct contact condensation on a thin water film flowing down on a glass sphere in vacuum cell, measurement of film temperature with a thermocouple
1987	Garnier et al. [24]	0.01	≈ 20–25	Direct contact condensation on NaCl aerosols in a cloud chamber with horizontal flow, tracing of the droplet trajectories with laser light, measurement of the plate temperatures with thermocouples
1989	Hagen et al. [27]	0.01	16	Droplet growth in a vertical expansion cloud chamber, measurement of droplet radius by light scattering, calculation of temperature from isentropic expansion
				Dynamically renewing surfaces
1961	Berman [9]	1	10	Film condensation on horizontal tube, no details about temperature measurement
1963	Nabavian and Bromley [66]	0.35–1	7–50	Film condensation on horizontal grooved tube, measurement of vapour temperature with a thermometer
1964	Goldstein [25]	≈ 0.1	25–30	Film condensation in shock tube, no details about temperature measurement
1964	Jamieson [38]	0.305	0–70	Direct contact condensation on water jet in radioactive steam (jet tensimeter), determination of condensation rate from activity, no details about temperature measurement
1965	Jamieson [39]	0.35		
1967	Mills and Seban [64]	0.45-1	7.6–10.2	Film condensation on vertical copper plate, measurement of temperature distribution in the plate
1968	Tanner et al. [92]	> 0.1	22–46	Dropwise condensation on vertical copper plate, measurement of block temperature with thermocouples
1969	Maa [55]	1	0.8–8.2	Direct contact condensation on falling water jet (jet stream tensimeter), calculation of the surface temperature from the jet bulk temperature
1969	Wenzel [101]	1.0	22–46	Film condensation experiments of Tanner et al. [92] measurement of block temperature with thermocouples
1971	Tamir and Hasson [90]	0.09–0.35	48.5–105.5	Direct contact condensation on thin flowing water film, interferometric measurement of the change in film thickness, no details about temperature measurement
1973	Vietti and Schuster [95]	0.21	–	Droplet growth in a steam-air atmosphere, measurement of droplet radius by light scattering, measurement of chamber temperature with a thermocouple
1975	Vietti and Pastook [96]	1	20.8–23.2	Droplet growth on atmospheric nuclei in a cloud chamber with vertical flow, measurement of droplet radius by light scattering, measurement of chamber temperature with a thermocouple
1976	Vietti and Fastook [97]	0.1–1	20	Droplet growth in a CO_2 atmosphere in a cloud chamber with vertical flow measurement of droplet radius by light scattering, measurement of chamber temperature with a thermocouple

1976	Bonacci et al. [10]	0.417–0.693 (avg. 0.55)	5.5–7.0	Condensation in a copper-embedded glass vessel, measurement of pressure drop due to condensation, measurement of copper block temperature with a thermocouple
1978, 1979	Neizvestnyj et al. [69,70,71]	0.3–1	20	Droplet growth on NaCl nuclei in a vertical, thermostated cloud chamber dermination of droplet radius by photography, no details about temperature measurement
1986	Hatamiya and Tanaka [29]30	0.2–0.6	6.9–26.9	Dropwise condensation on vertical copper cylinder, no details about temperature measurement

4. Pressure and temperature dependency

The condensation coefficient of water measured in direct contact condensation by Finkelstein and Tamir [21] can be correlated with a reference pressure of $p_0 = 1$ bar (Fig. 4):

$$\mathscr{K}_\mathrm{C}(p) = 5.9083 \cdot 10^{-3} \cdot \left(\frac{p}{p_0}\right)^{-1.3686} \tag{6}$$

In contrast to theoretical predictions [44], both coefficients decrease with increasing pressure (Figs. 3 and 4), which can be explained by real gas effects. A similar pressure dependency is well-known from film condensation of metal vapours [1,48,50,89].

Komnos [46] takes into account deviations of the vapour from the ideal gas behaviour by correlating the condensation coefficient of water with the specific vapour volume $v_\mathrm{v}(p)$:

$$\mathscr{K}_\mathrm{C}(p) = 0.05 \cdot \frac{v_\mathrm{v}(p)}{v_\mathrm{v}(p_0 = 1\ \mathrm{bar})} \quad (p \leq 70\ \mathrm{bar}) \tag{7}$$

The decline of the condensation coefficient with increasing pressure according to Eqs. (6) and (7) is shown in (Fig. 5). Although not obvious from theory [98], the experimental data imply the evaporation coefficient and the condensation coefficient of water to depend on both pressure and temperature.

5. Dynamic surface tension

For water, decreasing condensation and evaporation coefficients with time over two decades are reported by several authors [10,27,38,40]. Vietti and Fastook [97] observe a decline of the condensation coefficient from 1.0 to approximately 0.1 for water droplets in a CO_2 atmosphere. Declining evaporation and condensation coefficients with time are not only reported for water (dipole moment 1.8), but also for less polar fluids, e.g. R11 (dipole moment 0.5) [74,87].

Pure, freshly formed water surfaces show a higher surface tension than older ones. Lenard [52] in 1887 seems to be the first to observe a decrease in the surface tension of a water surface after its formation, a phenomenon termed as dynamic surface tension. The relaxation of the surface tension of water at different temperatures is depicted in Fig. 6 [84].

Typical relaxation times to reach stationary values of surface tension lie in the order of milliseconds. After the formation of a surface, the molecules need about 10^{-10} s to orientate. Thus other mechanisms than the orientation of the molecules at the interface must be involved. Pallasch [72] reports a dependency of the dynamic surface tension from the velocity of the

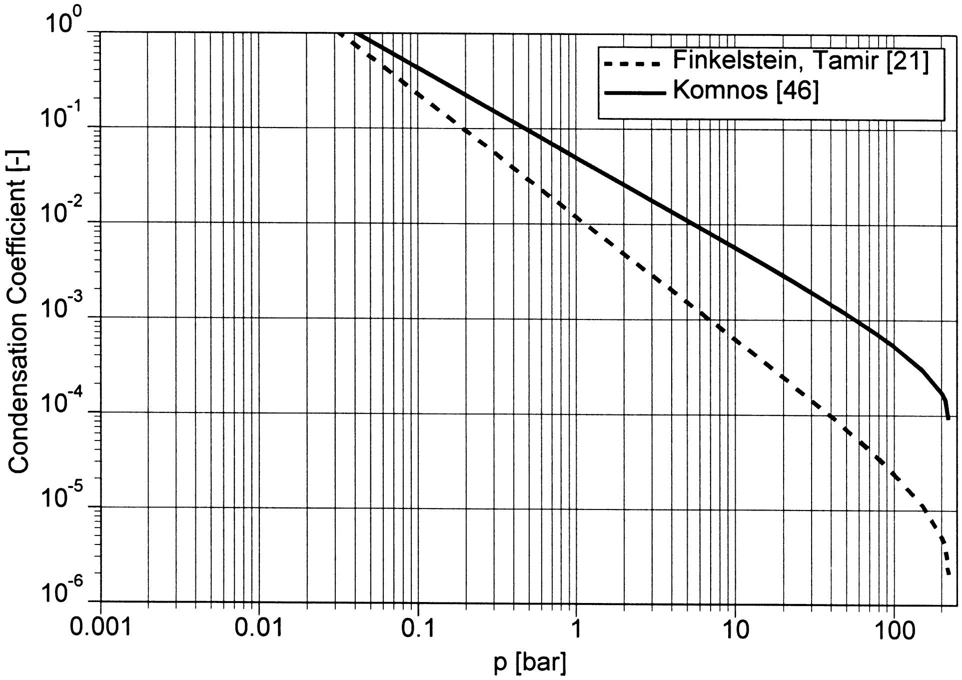

Fig. 5. Condensation coefficient of water at different pressures.

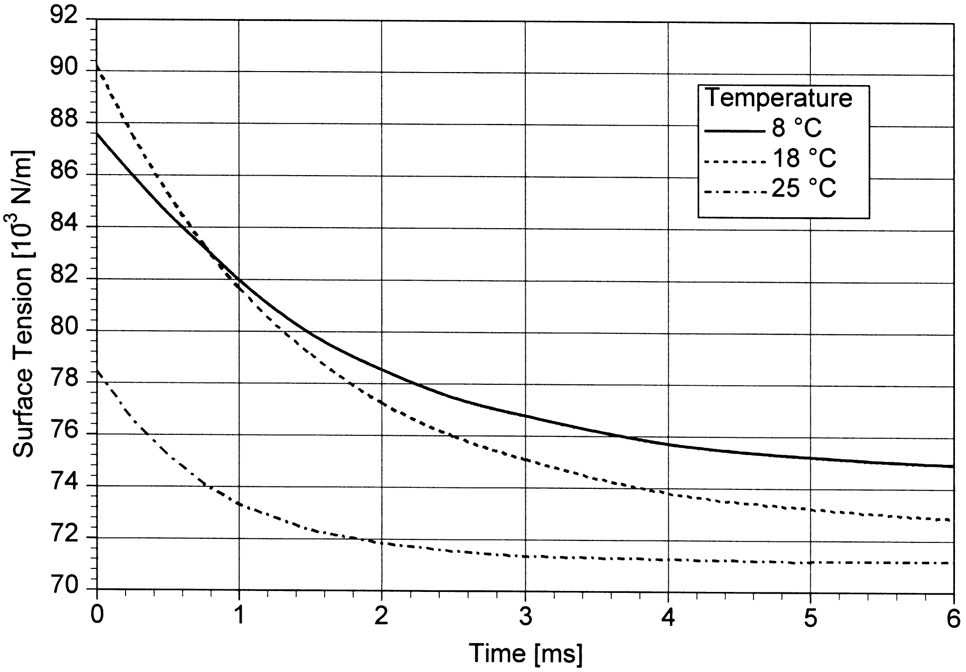

Fig. 6. Dynamic surface tension of water at different temperatures.

surface. For motions faster than 2 m/s, the surface should be regarded as dynamic.

Evaporation and condensation coefficients depend on the structure of the interface [102]. The energy for the molecules to separate from the interface or to be caught by it depends on the equilibrium of the interface. Just after their formation, surfaces do not have reached this equilibrium and therefore show higher evaporation and condensation coefficients. This is supported by jet tensiometer experiments [32,34,35,38,39,54–56] with exposure times of the jet of about 1 ms, when the static surface tension has not been reached yet (Fig. 6).

6. Surface active substances and impurities

Measuring the evaporation coefficient of mercury Knudsen [43] observed a similar scattering as with water. With a contaminated mercury surface, Knudsen found a value of 0.0005, while a cleaner surface yielded about 1/9, a value previously determined by Hertz [31]. For a very clean surface, an evaporation coefficient near unity was measured.

The surface of water is very sensitive to impurities. Contrary to alcohols and R113, Weinzierl [100] did not observe the onset of thermocapillary convection with water surfaces. Moreover, the velocity of a clean water surface induced by Marangoni convection is an order of magnitude higher compared to a surface with impurities [37].

Mache [57,58] noticed a strong reduction in the evaporation of water in glass vessels due to the accumulation of dissolved glass components on the water surface and the formation of a thin glass film. Glass vessels washed out by permanent use, however, showed a smaller reduction. The experiments of Prüger [76–79] confirmed Mache's glass effect. Cammenga et al. [12] determined an evaporation coefficient of 0.002 for water in a glass vessel. Replacing the glass vessel by a copper capillary evaporation coefficients two orders of magnitude higher between 0.25 and 0.38 were measured in the same apparatus.

Rideal [80] observed a reduction in the evaporation coefficient of 20 to 50% for water covered with different fatty acids. Experiments with alcohols as surface active substances show an even higher reduction of nearly two decades (Fig. 7). The enormous impediment of evaporation from water surfaces by surface active substances is also confirmed by experiments with mono glycerides, fatty acids, and fatty alcohols [82].

The smallest concentrations of a surface active substance in the range of some ppm reduce the evaporation coefficient of water to values around 3.5×10^{-5}

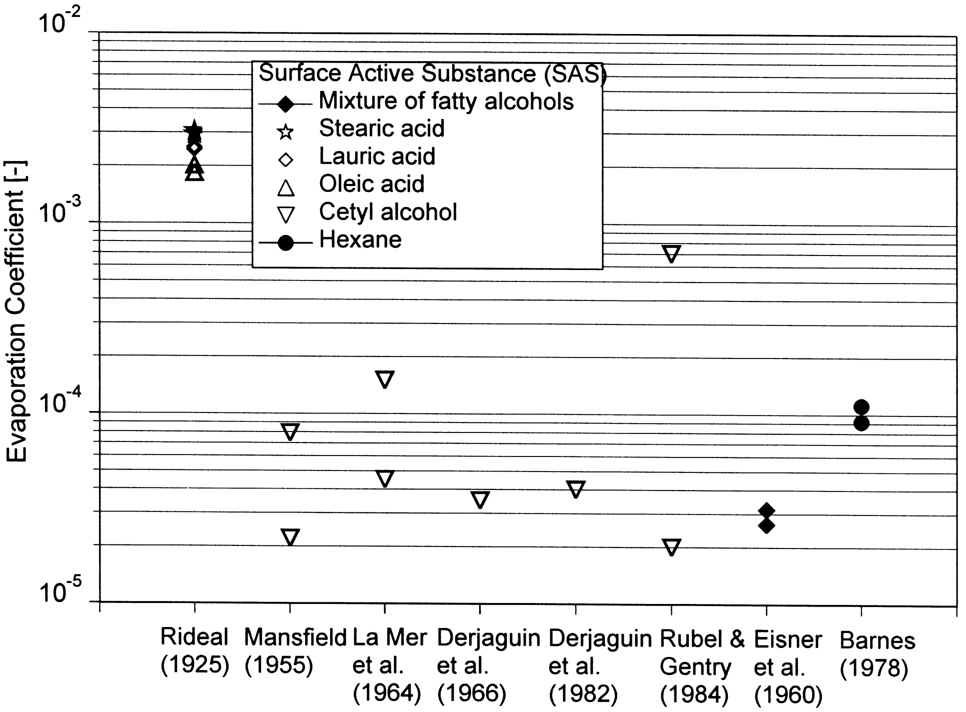

Fig. 7. Reduction of the evaporation coefficient of water by surface active substances.

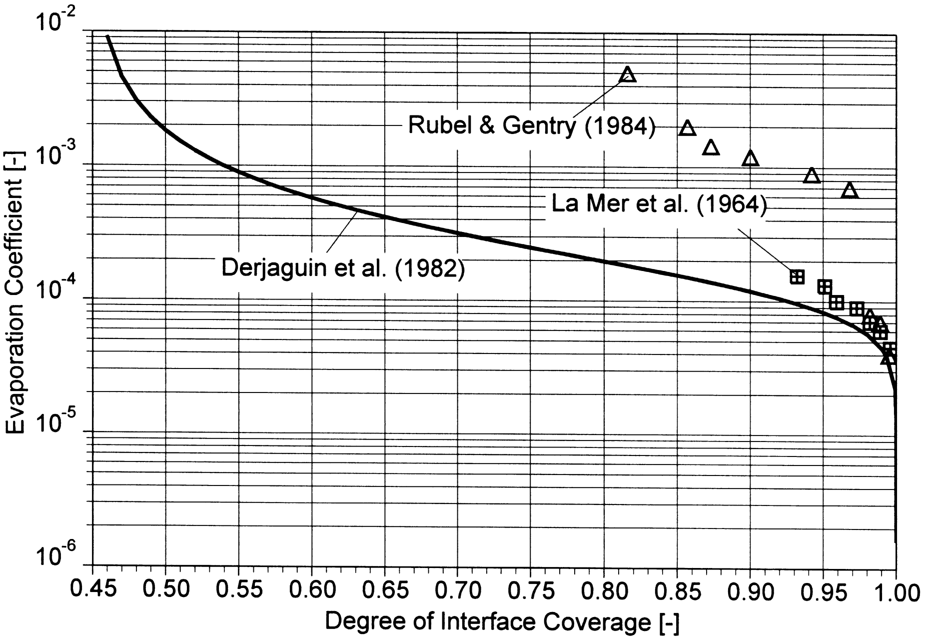

Fig. 8. Evaporation coefficient of water depending on the degree of interface coverage.

[18]. Similar results (6.8×10^{-5} with cetyl alcohol and 3.5×10^{-5} with fatty alcohols) are presented by Bakhanova et al. [6]. More decisive than the thickness of the layer of surface active molecules is their degree of interface coverage (Fig. 8) [19,51,83].

7. Conclusion

The frequently applied assumption that evaporation and condensation coefficients are constant properties of a substance is not confirmed by the analysis carried out for water. Evaporation and condensation coefficients of water obtained theoretically or experimentally rather scatter in a range of more than two decades with the condensation coefficient exceeding the evaporation coefficient. Both coefficients decrease with increasing temperature and increasing pressure.

Due to the dynamic surface tension and a reduced sensitivity to impurities, evaporation and condensation coefficients measured on dynamically renewing surfaces, such as jets or moving films, are higher than those on quasi-static, stagnant surfaces.

Surface active substances and impurities tend to accumulate at interfaces and reduce the evaporation and condensation coefficients of liquids. Even small contaminations of the surface significantly reduce the interfacial mass transfer. Evaporation and condensation in glass vessels can strongly be hindered by the accumulation of dissolved glass components on the interface.

An intensified research in both theoretical and experimental methods for the determination of evaporation and condensation coefficients is desirable. Furthermore, defining both coefficients to correlate experimental and theoretical mass transfer rates at an interface implies that real gas effects should be included in the equations of kinetic evaporation and condensation to provide better theoretical models for phase change processes.

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