EPFL

ChE-309 TP-2
Evaporation

instructions for use, spring 2025

TP assistant:
Sanjay Ventkatachalam
sanjay.venkatachalam@epfl.ch

Course Leader:
Wendy Queen
wendy.queen@epfl.ch

1. Declaration of the objective

The BALIS company in Germany, would like to study the possibility of concentrating one of their products: the " BALIS BASIL – BASIL GINGER DRINK" to reduce the shipping price for exporting to other countries. In addition, since 2021, this company announced proudly that every product from BALIS is climate neutral! They claimed that all CO_2 emissions generated during regional production are compensated for all varieties and all sales sizes. For this purpose, they are also looking for an option in which they can concentrate their product by consuming less heat energy and therefore producing less CO_2 for making that energy. In this experiment you are going to investigate one of these options, ***multi effect film evaporator,*** and demonstrate the benefit of this option by running a pilot evaporation experiment.

2. Theoretical basis

2.1 Introduction

Heat transfer to a boiling liquid is often used in industries. This step is known as *evaporation* in general. In evaporation, steam from a boiling liquid solution is removed and a more concentrated solution is obtained. In the majority of cases, the evaporation operation refers to the removal of water from an aqueous solution.

The concentration of solutions of sugar, sodium chloride, sodium hydroxide, glycerol, glue, milk or orange juice are typical examples where evaporation is used industrially. In these cases, the concentrated solution is the desired product and the evaporated water is normally removed. In some cases, water containing a small amount of mineral salts is evaporated a second time to provide water free of solids. It is then used as a power supply for boilers, for chemical processes or for other uses. Seawater evaporation plants have also been developed and used to provide drinking water. In some cases, the main purpose of evaporation is to concentrate the solution in such a way that during cooling the crystals of salt are formed and separated. This special evaporation process is called *crystallization.*

2.2 Important Process Factors

The physical and chemical properties of the concentrated solution and the removed steam have a great effect on the type of evaporator used, and on process pressure and temperature. Some of these properties, which affect transformation processes, are as follows:

1. Concentration of the liquid. Usually, the incoming flow of liquid into the evaporator is relatively diluted so that its viscosity is low, that is, similar to water. Thus, relatively high heat transfer coefficients are obtained. When evaporation takes place, the solution can become very concentrated and very viscous, causing a net drop in the heat transfer coefficient. Adequate circulation and/or turbulence must be present to maintain the coefficient at a sufficient value.

2. Solubility. As the solutions are heated and the concentration of solutes or salts increases, the solubility limit of the material in solution can be exceeded and crystals can form. This can limit the maximum concentration of solution that can be obtained by evaporation. In most cases, the solubility of the solute increases with temperature. This means that crystallization can occur when the hot concentrated solution from the evaporator is cooled to room temperature.

3. Sensitivity of materials to temperature. Many products, including food and other biological materials, can be temperature sensitive and degrade at higher temperatures or after prolonged heating. These products are pharmaceuticals, food products such as milk, orange juice and plant extracts and organic chemicals. Degradation depends on the temperature and duration of evaporation.

4. Foam formation. In some cases, materials contained in caustic solutions or food products such as skimmed milk and fatty acid solutions form a foam when boiling. This foam accompanies the steam coming out of the evaporator and induces losses.

5. Pressure and temperature. The boiling point of the solution is related to the pressure of the system. The greater the operating pressure of the evaporator, the greater the boiling temperature will be. In addition, as the concentration of the solute increases by evaporation, the boiling temperature increases. This phenomenon is called an increase in boiling point or elevation. To maintain a low temperature in the case of heat-sensitive materials, it is often necessary to operate under a pressure of 1 atm, or vacuum.

6. Deposit of tarter and *scale.* Some solutions deposit solids, called scale, on heating surfaces. These may be formed by decomposition or low solubility products. The result is the decrease in the overall heat transfer coefficient and the evaporator may need to be cleaned. The building materials from which the evaporator is made are of paramount importance to minimize corrosion.

2.3 Vertical-tubes evaporators

During evaporation, heat is added to a solution to vaporize the solvent which is usually water. Heat is provided by the condensation of a vapor on one side of a metal surface in contact with the liquid to be evaporated. The type of equipment used depends mainly on the configuration of the heat transfer surface and the means used to provide agitation or circulation of the liquid. For this experiment we will use a vertical type evaporator.

Vertical type evaporator with natural circulation. In this type of evaporator, vertical tubes are used. The liquid is inside the tubes and the steam condenses on the outside of the tubes. Due to boiling and decreasing density, the liquid rises into the tubes by natural circulation and flows downward through a large open space or central spillway. This natural circulation increases the heat transfer coefficient. It is not used in the case of viscous liquids.

An evaporator with long vertical tube is shown in Fig. 1, the liquid is inside the tubes.

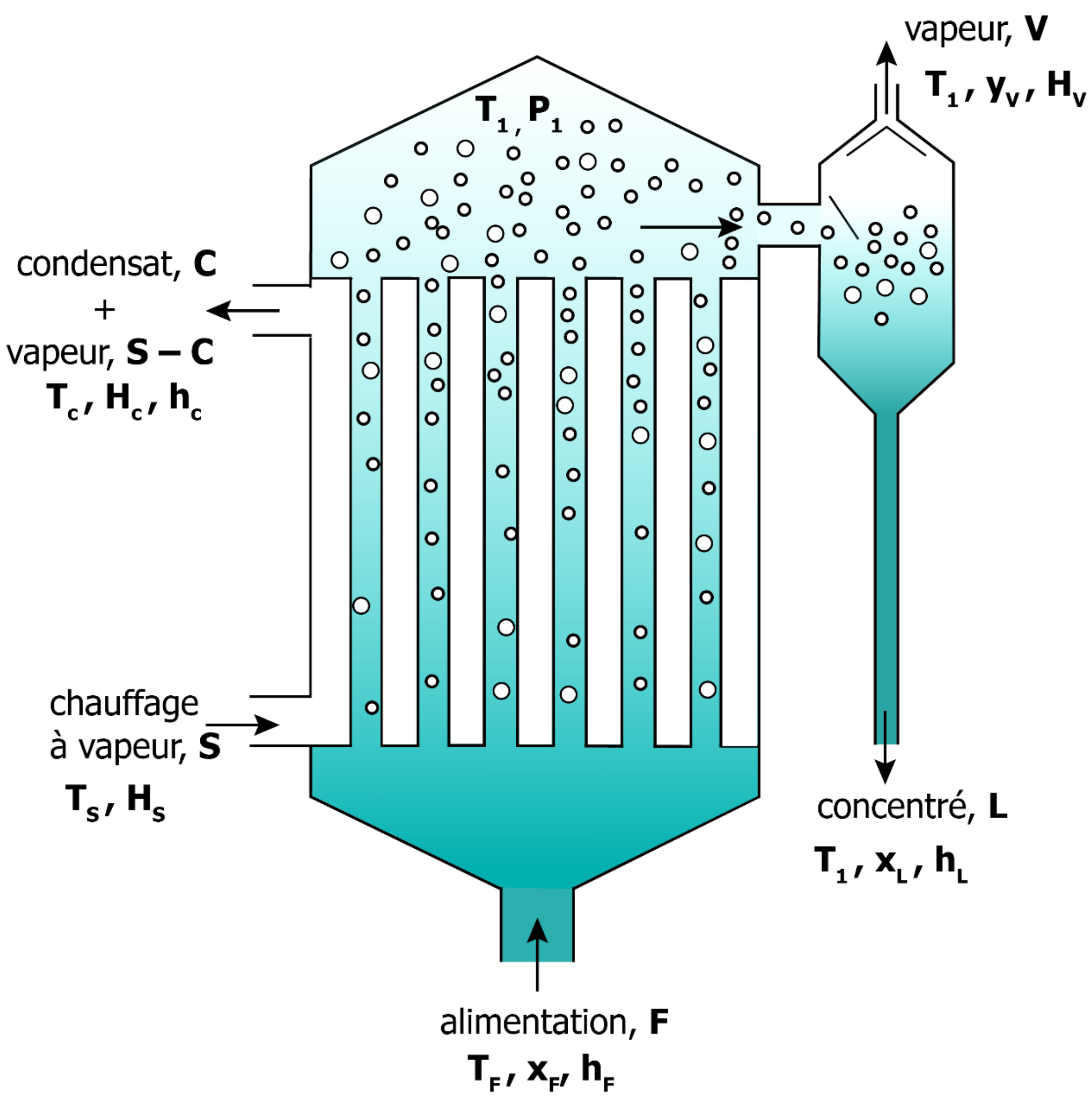


Figure 1. 1A long vertical tube evaporator with the high quantities for heat and mass for a single effect evaporator.

In industrial evaporators, the tubes are often 3 to 10 m long and the formation of steam bubbles in the tubes causes a pumping action giving very high flow speeds. In general, the liquid passes through the tubes only once and is not recirculated. Contact times can be very low in this type of evaporators. In some cases, such as when the ratio of the supply to the evaporation rate is low, the natural recirculation of the product through the evaporator is done by adding a large connection of tube between the output line of the concentrate and the supply duct. This is widely used for the production of condensed milk.

The variables and quantities important for the heat and mass balance for a single-effect evaporator are shown in Figure 1. The flow of the solution enters at T_F[*K or °C*] and the saturated steam at enters the heat exchange section at T_S. The condensed vapor comes out in the form of condensate or drops of liquid water. As a first approximation, we can assume that the solution that takes out the evaporator is perfectly mixed. Then the concentrated product and steam are at temperature T_1, which is the boiling point of the solution (at the pressure P_1, which is the vapor pressure of the solution).

The concept of an overall heat transfer coefficient is used in the calculation of the heat transfer rate in an evaporator. The equation for the vertical type evaporator (in the co-*current* configuration) shown in Figure 1 can be written as:

$$Q = UA\,\Delta T_{LM} = UA\,\frac{(\mathrm{T}_S - \mathrm{T}_F) - (\mathrm{T}_C - \mathrm{T}_1)}{\ln\left(\frac{\mathrm{T}_S - \mathrm{T}_F}{\mathrm{T}_C - \mathrm{T}_1}\right)} \quad (1)$$

Where ΔT_{LM}[*K*] is the temperature difference (logarithmic mean) between the steam and the boiling liquid in the evaporator and UA is an overall thermal transfer coefficient multiplied by the exchange surface area A. In order to solve Eq. 1 the value of Q in [*W*] must be determined by making heat and mass balances. The solution mass flow rate entering the evaporator is F [*kg/h*]. It has a solute fraction x_F [kg/kg], temperature T_F and enthalpy h_F[*J/kg*]. The outflow, i.e. the concentrated liquid L[*kg/h*] with an enthalpy h_L has a solute fraction of x_L and is also at T_1 . The vapour removed V [*kg/h*] is produced as a pure solvent with a solute content of $y_V = 0$, temperature,T_1 and enthalpy H_V. The steam flow for incoming heating is S [*kg/h*] and has a temperature of $T_S$and enthalpy H_S. It is possible that the steam does not condense completely, but comes out of the evaporator in the form of a mixture of saturated water vapor ($S - C$, [*kg/h*]) in equilibrium with the condense at (C, [*kg/h*]) at a temperature of T_C and with enthalpies of H_C and h_C, respectively.

For the material balance, as we are in the steady state, the incoming mass flow is equal to the outflow. So, for a total balance sheet (on the side of the solution),

$$F = L + V \quad (2)$$

For a balance on the solute (dissolved solid) alone,

$$Fx_F = Lx_L \quad (3)$$

For the heat balance:

Total incoming heat = Total outgoing heat – Heat loss (4)

Then an overall balance can be easily written using the enthalpies and flow rates shown in Figure 1. The latent heat of the steam at saturation temperatures can be obtained from the steam tables (see Annex). However, the enthalpies of the solutions are often not available. These enthalpy-concentration data are available only for a small number of substances in solution. Therefore, some approximations are made in order to make the heat balance.

2.4 Multiple effect evaporators

A single-effect evaporator as discussed above and also as shown in Fig. 2 below is wasteful of energy since the latent heat of the vapor leaving is not used but is discarded.

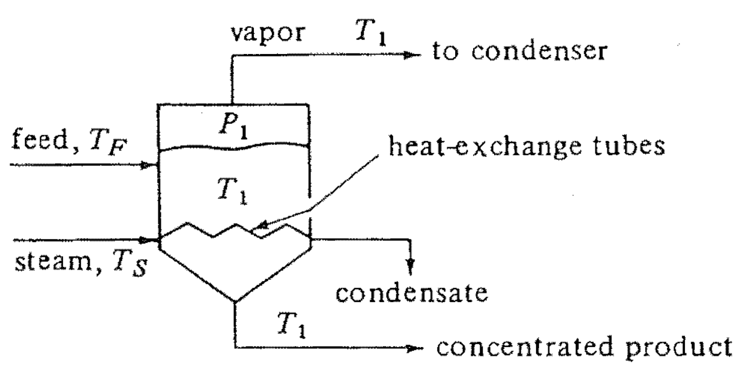


Figure 2. Simplified diagram of a single-effect evaporator.

However, much of this latent heat can be recovered and reused by employing multiple-effect evaporators. A simplified diagram of a forward-feed triple-effect evaporation system is shown in Fig. 3. If the feed temperature T_F to the first effect is near the boiling point at the pressure in the first effect (T_1), 1 kg of steam will evaporate almost 1 kg of solvent in the first effect (if the solvent is water). The first effect operates at a high-enough temperature so that the evaporated solvent serves as the heating medium to the second effect. Here, again, almost another kg of solvent is evaporated, which can be used as the heating medium to the third effect. As a very rough approximation, almost 3 kg of solvent will be evaporated for 1 kg of steam for a three-effect evaporator (if the solvent is water and in the ideal case without too much heat loss). Hence, the steam economy, which is kg vapor evaporated / kg steam used, is increased. This also approximately holds for a number of effects over three. However, this increased steam economy of a multiple-effect evaporator is gained at the expense of the original first cost of these evaporators.

In forward-feed operation as shown in Fig. 3, the fresh feed is added to the first effect and flows to the next in the same direction as the vapor flow. This method of operation is used when the feed is hot or when the final concentrated product might be damaged at high temperatures. Here the boiling temperatures decrease from effect to effect. This means that if the first effect is at P_1 1 atm abs pressure, the last effect will be under vacuum at a pressure P_3.

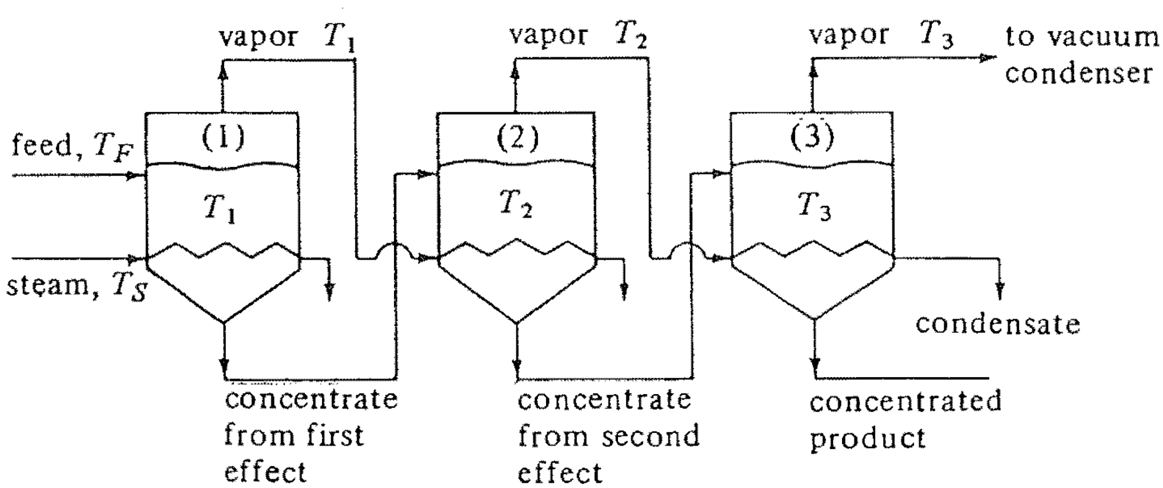


Figure 3. Simplified diagram of a triple-effect evaporator.

3. <u>Practical Laboratory Exercises</u>

3.1 Objectives

- Find the relation between liquid color and concentration with UV-Vis spectrometer
- Run the double effect evaporator at steady state
- Make the mass and energy balances for each effect
- Calculate the steam economy

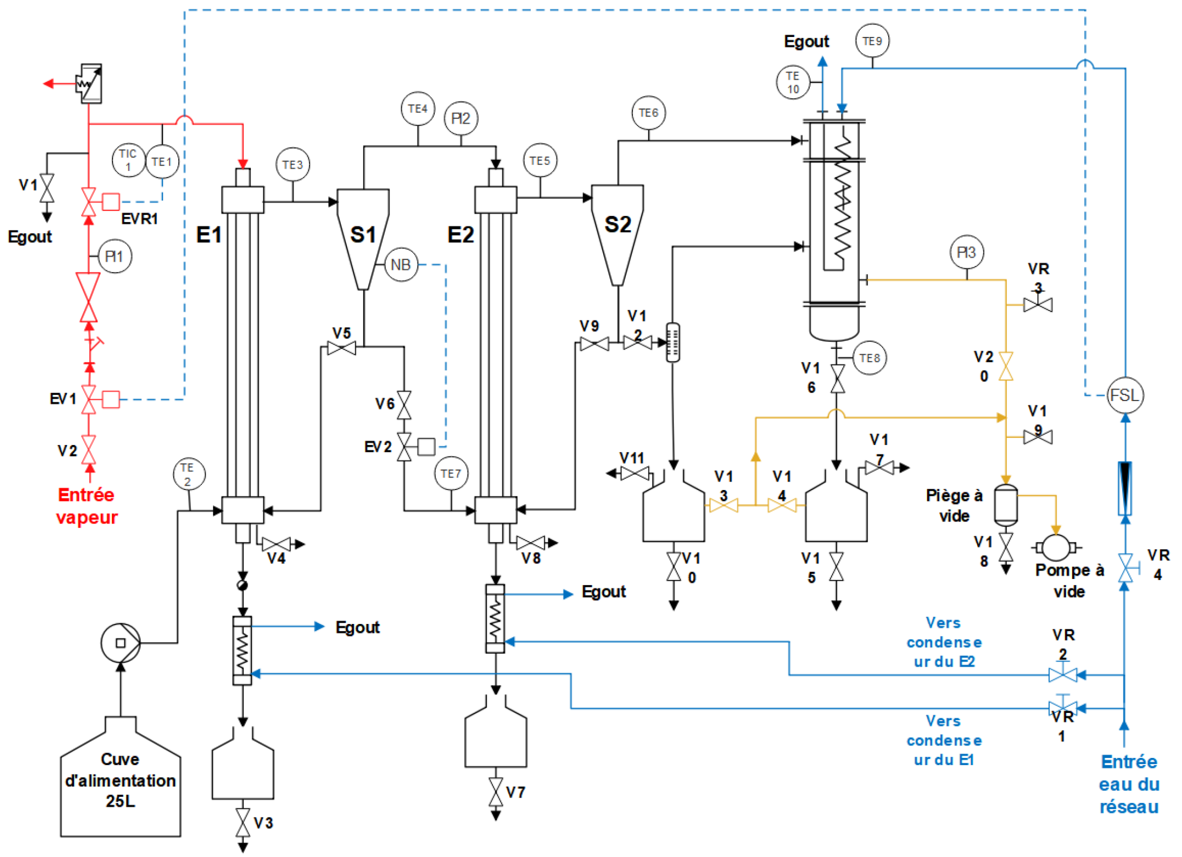
3.2 UV-Vis spectrometer

Prepare standard solutions of the solute in water with different concentration, ranging from 25 mg/L to 1 mg/L by diluting the most concentrated stock solution. Turn on the UV-Vis spectrometer and wait for 15 minutes to warm up. After recalibrating the system, open UV-Vis

Analyst software. Place the reference sample (here distilled water) to scan the baseline. Next perform a wavelength scanning between 400 to 700 nm (visible range) to find the peak with maximum intensity for one of your samples. Then based on the measured wavelength, do a single wavelength photometric measurement for all of your samples and write down the observed intensity and calculate the calibration equation.

Next prepare around 15 liters of the feed with concentration of about 2 mg/L.

3.3 Evaporator set-up



Startup & operation:

Warning: Read these instructions carefully and follow exactly the procedure !

1) Turn on the electrical control panel by rotating the switch and pressing the green lamp. Steam generator start-up: Check the inlet water valve is open and the outlet steam valve is closed. Press the "I/O" button on the steam unit to switch it on (the unit will be supplied with water automatically and heating will begin). The red lamps for water level should go on and the pump should whistle. After a few moments, the green lamp indicating the start of heating will go on. Wait until the pressure gauge indicates the operating pressure (8 bar) before

opening the steam valve at the back of the generator (which will be performed by the assistant).

2) Check the oil level of compressor and turn on the compressor to supply air for pneumatic control valve (EVP1). Check the cooling water of condensers are on (cooling water must be set at equal or more than 150 L/h otherwise the generated heat will be stopped automatically for safety reasons). Write down the cooling water flow rate from rotameter.

3) Open **slowly** the steam valve (the pipe may shake) and in line V2 valve. Check the steam pressure and adjust it if necessary using the regulator to about 1.2 bar via the PI1 manometer (the regulator is usually adjusted beforehand by the assistant). Open V21 and V22 and close V3.

4) Set the opening of valve EVP1 to 50% in manual mode. Allow the steam to circulate in the system for 2 to 3 minutes while purging the system of primary steam. In this step you may see some brownish water comes out which is common. Then set the EVP1 to 0% and close V22 so that the steam only passes through the steam trap. Now the steam is ready to use. Empty the brownish liquid from collector.

5) Close V5, V6 and V7 and switch on the feed pump and set the flow rate of the pump to 7 L/h to fill the evaporator E1 and a portion of the separator S1. When S1 is filled to the desired amount (check with assistant), change the flow rate to the value given by the assistant (different flow rates will be used for each group). Switch the control valve from manual to auto mode and set the temperature of the steam to 102°C. Check the alarm temperature to be at 120°C.

6) Once TE3 reaches close to 100°C, open V5 a little bit to allow recirculation of liquid in E1. Wait until TE4 reaches close to 100°C. Then drain the steam collector by opening V3 and measure the amount of condensed steam. This amount represents the amount of heat necessary for starting up the system. Then open V6 slowly and a little bit. Try to adjust this valve so that the rising liquid speed in the 2nd column (E2) is half of the first column. Close V1 and V9. Let the liquid fill half of E2.

7) Check all venting valves are closed and turn on the vacuum. When the level of liquid in E1 becomes low enough, open slightly V9. After film evaporation starts to occur open V1 slightly. Notice since you evaporate some portion of the feed, the exiting liquid from V1 must be less than the feed flow rate.

8) Keep eye on the level of liquid in evaporators and separators. By adjusting the 4 valves of V5, V6, V9 and V1 try to keep the level of liquid constant. As much as you can keep the system at steady state, steam economy will improve.

9) Keep a record of the volume of vapor condensed in the 3 collectors versus time every 15 mins.

Shut down:

1) Turn off the steam, feed and vacuum. Slightly open the vent valve V19 to pressurize the system to atmospheric pressure.

2) Empty all the collectors and the columns and measure the weight of liquid in each section. Measure the concentrations.

3) Change the feed to distilled water and set the flow rate of the pump to 7 L/hr to wash the system.

4) After washing the system, close the steam valve at the back of the steam generator and turn off the steam generator. Set the control valve to 50% for some minutes in manual mode to empty the remaining of steam in the lines.

5) Turn off the compressor and after downloading your data, turn off the electrical panel and close only the main valve of cooling water.

4. <u>Report</u>

Present your calibration line.

How do you determine that steady state is achieved in the system?

Present mass & energy balance for each effect separately and overall with both graphical representation and mathematical calculations.

Present the results obtained (final concentrations, steam economy, etc.) and explain how you could get better efficiency if you could have repeated this experiment once more.

Based on given dimensions of evaporator column in the annex, calculate heat transfer coefficient (U, W/m^2K) for both E1 and E2.

Discuss and calculate, in the case of ideal operation (steam economy =2), and considering the same feed flow rate, and the same final concentration, what would be the flow rate of steam required?

How do you think operational parameters like steam temperature, size of E1 & E2, feed flow rate, vacuum pressure can affect final concentration and steam economy?

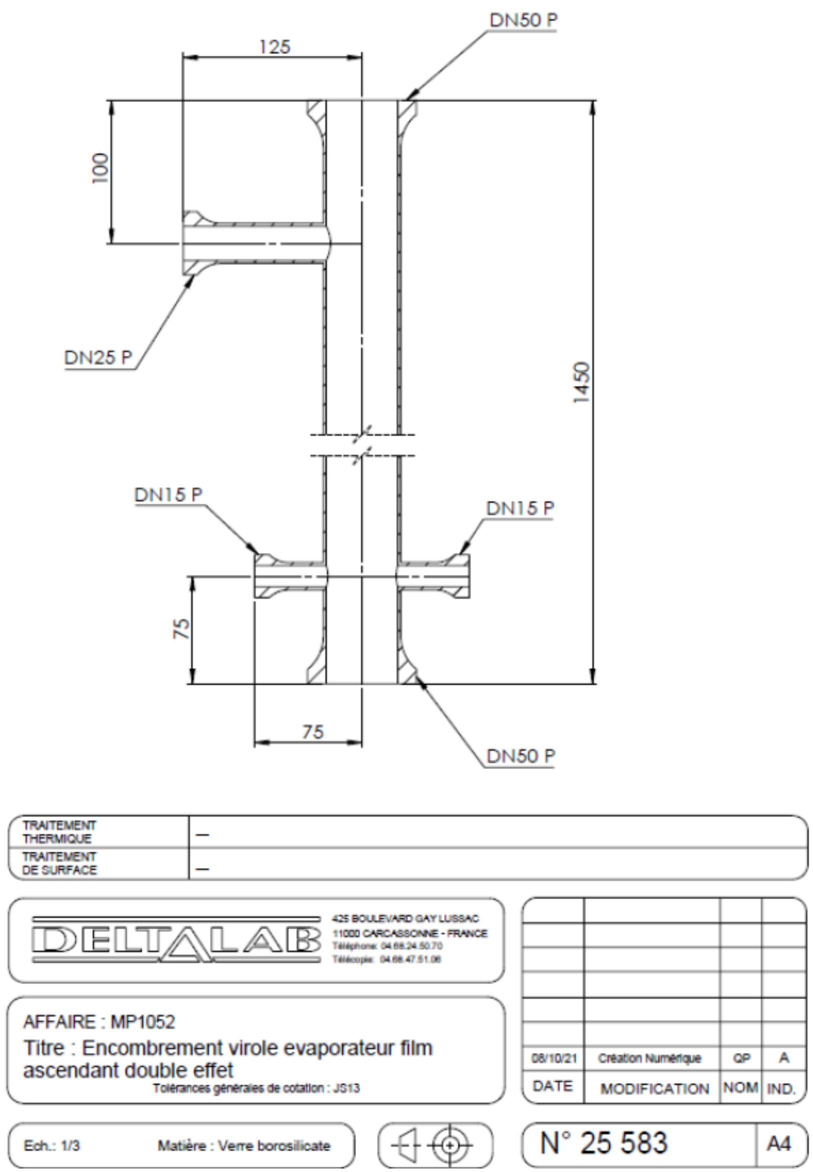
Saturated Water and Steam (Temperature-based)

T	p_{sat}	Volume, m^3/kg		Energy, kJ/kg		Enthalpy, kJ/kg			Entropy, kJ/(kg K)		
℃	MPa	v_f	v_g	u_f	u_g	h_f	h_g	h_{fg}	s_f	s_g	s_{fg}
0.01	0.0006117	0.00100021	205.991	**0**	2374.9	0.00	2500.9	2500.9	**0**	9.1555	9.1555
1	0.0006571	0.00100015	192.439	4.18	2376.2	4.18	2502.7	2498.6	0.01526	9.1291	9.1138
2	0.0007060	0.00100011	179.758	8.39	2377.7	8.39	2504.6	2496.2	0.03061	9.1027	9.0720
3	0.0007581	0.00100008	168.008	12.60	2379.0	12.60	2506.4	2493.8	0.04589	9.0765	9.0306
4	0.0008135	0.00100007	157.116	16.81	2380.4	16.81	2508.2	2491.4	0.06110	9.0505	8.9894
5	0.0008726	0.00100008	147.011	21.02	2381.8	21.02	2510.1	2489.0	0.07625	9.0248	8.9486
6	0.0009354	0.00100011	137.633	25.22	2383.2	25.22	2511.9	2486.7	0.09134	8.9993	8.9080
7	0.0010021	0.00100014	128.923	29.43	2384.5	29.43	2513.7	2484.3	0.10637	8.9741	8.8677
8	0.0010730	0.00100020	120.829	33.63	2386.0	33.63	2515.6	2481.9	0.12133	8.9491	8.8278
9	0.0011483	0.00100026	113.304	37.82	2387.3	37.82	2517.4	2479.6	0.13624	8.9243	8.7881
10	0.0012282	0.00100035	106.303	42.02	2388.6	42.02	2519.2	2477.2	0.15109	8.8998	8.7487
11	0.0013130	0.00100044	99.787	46.22	2390.0	46.22	2521.0	2474.8	0.16587	8.8754	8.7096
12	0.0014028	0.00100055	93.719	50.41	2391.4	50.41	2522.9	2472.5	0.18061	8.8513	8.6707
13	0.0014981	0.00100067	88.064	54.60	2392.8	54.60	2524.7	2470.1	0.19528	8.8274	8.6321
14	0.0015990	0.00100080	82.793	58.79	2394.1	58.79	2526.5	2467.7	0.20990	8.8037	8.5938
15	0.0017058	0.00100094	77.875	62.98	2395.5	62.98	2528.3	2465.4	0.22446	8.7803	8.5558
16	0.0018188	0.00100110	73.286	67.17	2396.9	67.17	2530.2	2463.0	0.23897	8.7570	8.5180
17	0.0019384	0.00100127	69.001	71.36	2398.2	71.36	2532.0	2460.6	0.25343	8.7339	8.4805
18	0.0020647	0.00100145	64.998	75.54	2399.6	75.54	2533.8	2458.3	0.26783	8.7111	8.4433
19	0.0021983	0.00100164	61.256	79.73	2400.9	79.73	2535.6	2455.9	0.28218	8.6884	8.4063
20	0.0023393	0.00100184	57.757	83.91	2402.3	83.91	2537.4	2453.5	0.29648	8.6660	8.3695
21	0.0024882	0.00100205	54.483	88.10	2403.7	88.10	2539.3	2451.2	0.31073	8.6437	8.3330
22	0.0026453	0.00100228	51.418	92.28	2405.1	92.28	2541.1	2448.8	0.32493	8.6217	8.2967
23	0.0028111	0.00100251	48.548	96.46	2406.4	96.46	2542.9	2446.4	0.33908	8.5998	8.2607
24	0.0029858	0.00100275	45.858	100.65	2407.8	100.65	2544.7	2444.0	0.35318	8.5781	8.2250
25	0.0031699	0.00100301	43.337	104.83	2409.1	104.83	2546.5	2441.7	0.36722	8.5566	8.1894
26	0.0033639	0.00100327	40.973	109.01	2410.5	109.01	2548.3	2439.3	0.38123	8.5353	8.1541
27	0.0035681	0.00100354	38.754	113.19	2411.8	113.19	2550.1	2436.9	0.39518	8.5142	8.1191
28	0.0037831	0.00100382	36.672	117.37	2413.2	117.37	2551.9	2434.6	0.40908	8.4933	8.0842
29	0.0040092	0.00100411	34.716	121.55	2414.5	121.55	2553.7	2432.2	0.42294	8.4725	8.0496
30	0.0042470	0.00100441	32.878	125.73	2415.9	125.73	2555.5	2429.8	0.43675	8.4520	8.0152
31	0.0044969	0.00100472	31.151	129.91	2417.2	129.91	2557.3	2427.4	0.45052	8.4316	7.9810
32	0.0047596	0.00100504	29.526	134.09	2418.7	134.09	2559.2	2425.1	0.46424	8.4113	7.9471
33	0.0050354	0.00100537	27.998	138.26	2420.0	138.27	2561.0	2422.7	0.47792	8.3913	7.9134
34	0.0053251	0.00100570	26.560	142.44	2421.4	142.45	2562.8	2420.3	0.49155	8.3714	7.8799
35	0.0056290	0.00100605	25.205	146.62	2422.6	146.63	2564.5	2417.9	0.50513	8.3517	7.8466
36	0.0059479	0.00100640	23.929	150.80	2424.0	150.81	2566.3	2415.5	0.51867	8.3321	7.8135
37	0.0062823	0.00100676	22.727	154.98	2425.3	154.99	2568.1	2413.1	0.53217	8.3127	7.7806
38	0.0066328	0.00100713	21.593	159.16	2426.7	159.17	2569.9	2410.8	0.54562	8.2935	7.7479
39	0.0070002	0.00100750	20.524	163.34	2428.0	163.35	2571.7	2408.4	0.55903	8.2745	7.7154
40	0.0073849	0.00100789	19.515	167.52	2429.4	167.53	2573.5	2406.0	0.57240	8.2555	7.6831

T	p_{sat}	Volume, m^3/kg		Energy, kJ/kg		Enthalpy, kJ/kg			Entropy, kJ/(kg K)		
°C	MPa	v_f	v_g	u_f	u_g	h_f	h_g	h_{fg}	s_f	s_g	s_{fg}
40	0.0073849	0.00100789	19.515	167.52	2429.4	167.53	2573.5	2406.0	0.57240	8.2555	7.6831
41	0.0077878	0.00100828	18.563	171.70	2430.7	171.71	2575.3	2403.6	0.58573	8.2368	7.6511
42	0.0082096	0.00100868	17.664	175.88	2432.1	175.89	2577.1	2401.2	0.59901	8.2182	7.6192
43	0.0086508	0.00100909	16.814	180.06	2433.4	180.07	2578.9	2398.8	0.61225	8.1998	7.5875
44	0.0091124	0.00100950	16.011	184.24	2434.7	184.25	2580.6	2396.4	0.62545	8.1815	7.5560
45	0.0095950	0.00100992	15.252	188.42	2436.1	188.43	2582.4	2394.0	0.63861	8.1633	7.5247
46	0.010099	0.00101036	14.534	192.61	2437.4	192.62	2584.2	2391.6	0.65173	8.1453	7.4936
47	0.010627	0.00101079	13.855	196.79	2438.8	196.80	2586.0	2389.2	0.66481	8.1275	7.4627
48	0.011177	0.00101124	13.212	200.97	2440.1	200.98	2587.8	2386.8	0.67785	8.1098	7.4320
49	0.011752	0.00101169	12.603	205.15	2441.4	205.16	2589.5	2384.4	0.69085	8.0922	7.4014
50	0.012352	0.00101215	12.027	209.33	2442.7	209.34	2591.3	2381.9	0.70381	8.0748	7.3710
51	0.012978	0.00101262	11.481	213.51	2444.1	213.52	2593.1	2379.5	0.71673	8.0576	7.3408
52	0.013631	0.00101309	10.963	217.70	2445.4	217.71	2594.8	2377.1	0.72961	8.0404	7.3108
53	0.014312	0.00101357	10.472	221.88	2446.7	221.89	2596.6	2374.7	0.74245	8.0234	7.2810
54	0.015022	0.00101406	10.006	226.05	2448.0	226.07	2598.3	2372.3	0.75526	8.0066	7.2513
55	0.015762	0.00101455	9.5643	230.24	2449.3	230.26	2600.1	2369.8	0.76802	7.9898	7.2218
56	0.016533	0.00101505	9.1448	234.42	2450.6	234.44	2601.8	2367.4	0.78075	7.9732	7.1925
57	0.017336	0.00101556	8.7466	238.60	2452.0	238.62	2603.6	2365.0	0.79344	7.9568	7.1633
58	0.018171	0.00101608	8.3683	242.79	2453.2	242.81	2605.3	2362.5	0.80610	7.9404	7.1343
59	0.019041	0.00101660	8.0089	246.97	2454.6	246.99	2607.1	2360.1	0.81871	7.9242	7.1055
60	0.019946	0.00101713	7.6672	251.16	2455.9	251.18	2608.8	2357.7	0.83129	7.9081	7.0769
61	0.020888	0.00101766	7.3424	255.35	2457.2	255.37	2610.6	2355.2	0.84384	7.8922	7.0484
62	0.021867	0.00101821	7.0335	259.53	2458.5	259.55	2612.3	2352.8	0.85634	7.8764	7.0200
63	0.022885	0.00101875	6.7396	263.72	2459.8	263.74	2614.0	2350.3	0.86882	7.8607	6.9918
64	0.023943	0.00101931	6.4598	267.91	2461.1	267.93	2615.8	2347.8	0.88125	7.8451	6.9638
65	0.025042	0.00101987	6.1935	272.09	2462.4	272.12	2617.5	2345.4	0.89365	7.8296	6.9359
66	0.026183	0.00102044	5.9399	276.27	2463.7	276.30	2619.2	2342.9	0.90602	7.8142	6.9082
67	0.027368	0.00102101	5.6984	280.46	2465.0	280.49	2621.0	2340.5	0.91835	7.7990	6.8807
68	0.028599	0.00102159	5.4682	284.65	2466.3	284.68	2622.7	2338.0	0.93064	7.7839	6.8532
69	0.029876	0.00102218	5.2488	288.84	2467.6	288.87	2624.4	2335.5	0.94291	7.7689	6.8260
70	0.031201	0.00102277	5.0395	293.04	2468.9	293.07	2626.1	2333.0	0.95513	7.7540	6.7989
71	0.032575	0.00102337	4.8400	297.23	2470.1	297.26	2627.8	2330.5	0.96733	7.7392	6.7719
72	0.034000	0.00102398	4.6496	301.42	2471.4	301.45	2629.5	2328.1	0.97949	7.7246	6.7451
73	0.035478	0.00102459	4.4680	305.60	2472.7	305.64	2631.2	2325.6	0.99161	7.7100	6.7184
74	0.037009	0.00102521	4.2945	309.80	2474.0	309.84	2632.9	2323.1	1.0037	7.6955	6.6918
75	0.038595	0.00102584	4.1289	313.99	2475.2	314.03	2634.6	2320.6	1.0158	7.6812	6.6654
76	0.040239	0.00102647	3.9708	318.18	2476.5	318.22	2636.3	2318.1	1.0278	7.6670	6.6392
77	0.041941	0.00102710	3.8197	322.38	2477.8	322.42	2638.0	2315.6	1.0398	7.6528	6.6130
78	0.043703	0.00102775	3.6752	326.58	2479.1	326.62	2639.7	2313.0	1.0517	7.6388	6.5871
79	0.045527	0.00102840	3.5372	330.76	2480.3	330.81	2641.3	2310.5	1.0637	7.6249	6.5612
80	0.047414	0.00102905	3.4052	334.96	2481.5	335.01	2643.0	2308.0	1.0756	7.6111	6.5355

T °C	p_{sat} MPa	Volume, m^3/kg		Energy, kJ/kg		Enthalpy, kJ/kg			Entropy, kJ/(kg K)		
		v_f	v_g	u_f	u_g	h_f	h_g	h_{fg}	s_f	s_g	s_{fg}
80	0.047414	0.00102905	3.4052	334.96	2481.5	335.01	2643.0	2308.0	1.0756	7.6111	6.5355
81	0.049367	0.00102972	3.2789	339.16	2482.8	339.21	2644.7	2305.5	1.0874	7.5973	6.5099
82	0.051387	0.00103038	3.1581	343.36	2484.1	343.41	2646.4	2302.9	1.0993	7.5837	6.4844
83	0.053476	0.00103106	3.0425	347.55	2485.3	347.61	2648.0	2300.4	1.1111	7.5702	6.4591
84	0.055635	0.00103174	2.9318	351.75	2486.6	351.81	2649.7	2297.9	1.1229	7.5567	6.4339
85	0.057867	0.00103243	2.8258	355.95	2487.8	356.01	2651.3	2295.3	1.1346	7.5434	6.4088
86	0.060173	0.00103312	2.7244	360.16	2489.1	360.22	2653.0	2292.8	1.1463	7.5302	6.3838
87	0.062556	0.00103382	2.6271	364.36	2490.3	364.42	2654.6	2290.2	1.1580	7.5170	6.3590
88	0.065017	0.00103452	2.5340	368.56	2491.5	368.63	2656.3	2287.6	1.1696	7.5040	6.3343
89	0.067558	0.00103524	2.4447	372.76	2492.7	372.83	2657.9	2285.1	1.1813	7.4910	6.3097
90	0.070182	0.00103595	2.3591	376.97	2493.9	377.04	2659.5	2282.5	1.1929	7.4781	6.2853
91	0.072890	0.00103668	2.2770	381.17	2495.2	381.25	2661.2	2279.9	1.2044	7.4653	6.2609
92	0.075684	0.00103741	2.1982	385.38	2496.4	385.46	2662.8	2277.3	1.2160	7.4526	6.2367
93	0.078568	0.00103814	2.1227	389.59	2497.6	389.67	2664.4	2274.7	1.2275	7.4400	6.2126
94	0.081541	0.00103888	2.0502	393.80	2498.8	393.88	2666.0	2272.1	1.2389	7.4275	6.1886
95	0.084608	0.00103963	1.9806	398.00	2500.0	398.09	2667.6	2269.5	1.2504	7.4151	6.1647
96	0.087771	0.00104038	1.9137	402.21	2501.2	402.30	2669.2	2266.9	1.2618	7.4027	6.1409
97	0.091030	0.00104114	1.8496	406.43	2502.4	406.52	2670.8	2264.3	1.2732	7.3904	6.1172
98	0.094390	0.00104191	1.7879	410.63	2503.6	410.73	2672.4	2261.7	1.2846	7.3783	6.0937
99	0.097852	0.00104268	1.7287	414.85	2504.8	414.95	2674.0	2259.0	1.2959	7.3661	6.0702
100	0.10142	0.00104346	1.6718	419.06	2506.0	419.17	2675.6	2256.4	1.3072	7.3541	6.0469
101	0.10509	0.00104425	1.6171	423.28	2507.2	423.39	2677.1	2253.8	1.3185	7.3422	6.0237
102	0.10887	0.00104504	1.5644	427.50	2508.4	427.61	2678.7	2251.1	1.3297	7.3303	6.0006
103	0.11277	0.00104583	1.5139	431.71	2509.6	431.83	2680.3	2248.5	1.3410	7.3185	5.9775
104	0.11678	0.00104664	1.4652	435.93	2510.7	436.05	2681.8	2245.8	1.3522	7.3068	5.9546
105	0.12090	0.00104744	1.4184	440.14	2511.9	440.27	2683.4	2243.1	1.3633	7.2952	5.9318
106	0.12515	0.00104826	1.3733	444.37	2513.0	444.50	2684.9	2240.4	1.3745	7.2836	5.9091
107	0.12952	0.00104908	1.3300	448.59	2514.2	448.73	2686.5	2237.7	1.3856	7.2721	5.8865
108	0.13401	0.00104991	1.2882	452.81	2515.4	452.95	2688.0	2235.1	1.3967	7.2607	5.8640
109	0.13863	0.00105074	1.2480	457.03	2516.5	457.18	2689.5	2232.4	1.4078	7.2493	5.8416
110	0.14338	0.00105158	1.2093	461.27	2517.7	461.42	2691.1	2229.6	1.4188	7.2381	5.8193
111	0.14826	0.00105243	1.1720	465.49	2518.8	465.65	2692.6	2226.9	1.4298	7.2269	5.7970
112	0.15328	0.00105328	1.1361	469.72	2520.0	469.88	2694.1	2224.2	1.4408	7.2157	5.7749
113	0.15844	0.00105414	1.1014	473.95	2521.1	474.12	2695.6	2221.5	1.4518	7.2047	5.7529
114	0.16374	0.00105500	1.0680	478.18	2522.2	478.35	2697.1	2218.7	1.4628	7.1937	5.7309
115	0.16918	0.00105588	1.0358	482.41	2523.4	482.59	2698.6	2216.0	1.4737	7.1828	5.7091
116	0.17477	0.00105675	0.99522	486.65	2526.2	486.83	2700.1	2213.2	1.4846	7.1719	5.6873
117	0.18052	0.00105764	0.97486	490.89	2525.5	491.08	2701.5	2210.5	1.4954	7.1611	5.6657
118	0.18641	0.00105853	0.94598	495.12	2526.7	495.32	2703.0	2207.7	1.5063	7.1504	5.6441
119	0.19246	0.00105942	0.91811	499.36	2527.8	499.56	2704.5	2204.9	1.5171	7.1397	5.6226
120	0.19867	0.00106033	0.89121	503.60	2528.8	503.81	2705.9	2202.1	1.5279	7.1291	5.6012

Glass shell dimensions:



Interior metallic part dimensions: