11. Problem №15: Heat and Temperature

11.1.. Solution of Brazil

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The Problem

A tube passes steam from a container of boiling water into a saturated aqueous salt solution. Can it be heated by the steam to a temperature greater than 100°C? Investigate the phenomenon.

1. Theoretical Approach

1.1 Definitions

Heat is the thermal energy in transit between two bodies with a difference in their temperatures.

And temperature, according to Statistical Mechanics, is a crescent function which varies with the number of accessible states of organization that a system has. And this number of accessible states of the system is a crescent function of the energy it possesses.

It happens that a certain system can't sustain any amount of energy with the same type of configuration. When the energy the system has reaches a certain level, the system has to drastically change its organization. It is a change in the physical state of the matter. A curious fact is that while the system is suffering a change in its physical state, all the energy absorbed is used for this proposal, meaning the temperature of the system does not change. Actually, this is used for the division of heat in two different definitions: Sensitive Heat, which varies the system's temperature; and Latent Heat, which does not vary the system's temperature.

For example, when energy is rapidly injected into a liquid system, it suffers a transformation called ebullition, that is, it goes from liquid state to the vaporized state while the temperature remains constant.

The constant value of the temperature during the ebullition is called Ebullition Point and it is the critical value in which the system can remain in the liquid state.

The Ebullition Point is determined by the Vapor Pressure of the System.

The Vapor Pressure is the pressure applied by the vapor when this is in equilibrium with the liquid which originated it, and is a crescent function of the temperature of the system. When the Vapor Pressure reaches the pressure applied on it by the ambient, the system enters in ebullition. Therefore a higher pressure means a higher ebullition point.

The Vapor Pressure of the system is determined by the type of particles it is formed. If the system is not of uniform composition, like a mix of salt and water, we have to take into consideration the Colligative Properties, which are properties of interaction between the different particles in the system. There is a colligative property called Ebullioscopy which guarantees us that when we add a solute to a solvent, the ebullition point of the system increases. This means that a solution of salt and water can reach a higher temperature than a pure water solution, without changing its physical state.

There is another colligative property which happens when the solvent of the solution is polar. It says that an ion of the dissociated salt may attach to the correspondent part of the polar molecule of the solvent, without breaking its intra-molecular forces. This interaction is so strong that when it happens, the solute may even stay attached to the solvent molecule after it suffers vaporization. It happens that when the solvation happens, due to the strengthening of the resultant intermolecular forces, the ebullition point of the resultant molecule also rises.

2. Experimental Approach

2.1 Objectives

To determine if the energy transfer mentioned in the problem is indeed possible, and to determine if it only happens with salt solutions.

2.2 Methodology

To do exactly the proposed, that is, try to heat an aqueous salt saturated solution to a temperature higher than the ebullition point of the only source of heat to the system: the vapor.

To do that, we realized that we would have to confine the vapor to re-direct it to the salty solution. But we would not be able to do that without raising the pressure of the water system, having as a consequence a rise in its ebullition point. So, we decided to build a system which would have a steady pressure value in all its extension, and we would only have to change our base values for comparison of temperatures, meaning that we'd have to raise the salty solution's temperature to a value higher than the new ebullition point of the water, already adjusted to the new pressure.

2.3 Materials

We used the following materials: Thermometers, Electric Heaters, Pressure Cooker, Plastic Tube, Calorimeter, Different kinds of Salts (NaCl, KCl), coffee, and Distilled Water.

2.4 Experimental Setup

Our calorimeter had two outlet holes; in one of them, we inserted a thermometer and in the other, a plastic tube. The other end of the plastic tube, we connected in the outlet valve of our cooker, which also had an outlet hole for another thermometer.

We inserted the thermometers in the outlet holes and sealed the ones in the pressure cooker, but not the ones in the small recipient, so that the vapor would be able to go out through the small recipient.

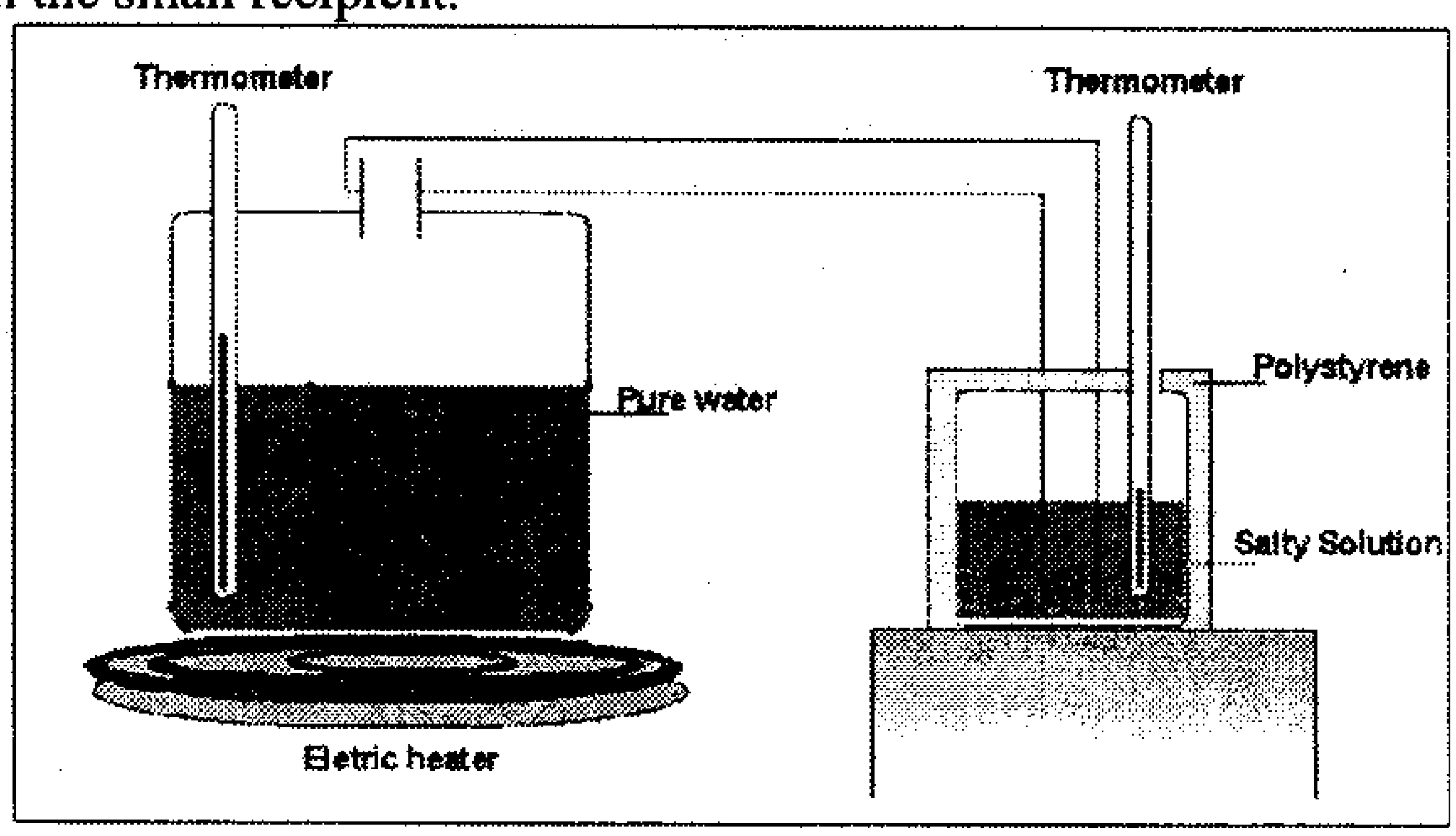


Fig.1 Setup

2.5 Procedure

To initiate our experimental analysis, we had to establish the base ebullition point of water inside our system, under its equilibrium pressure (The equilibrium pressure was the pressure of the system when the amount of vapor produced in the cooker was the same amount of vapor going out the outlet holes in the small recipient).

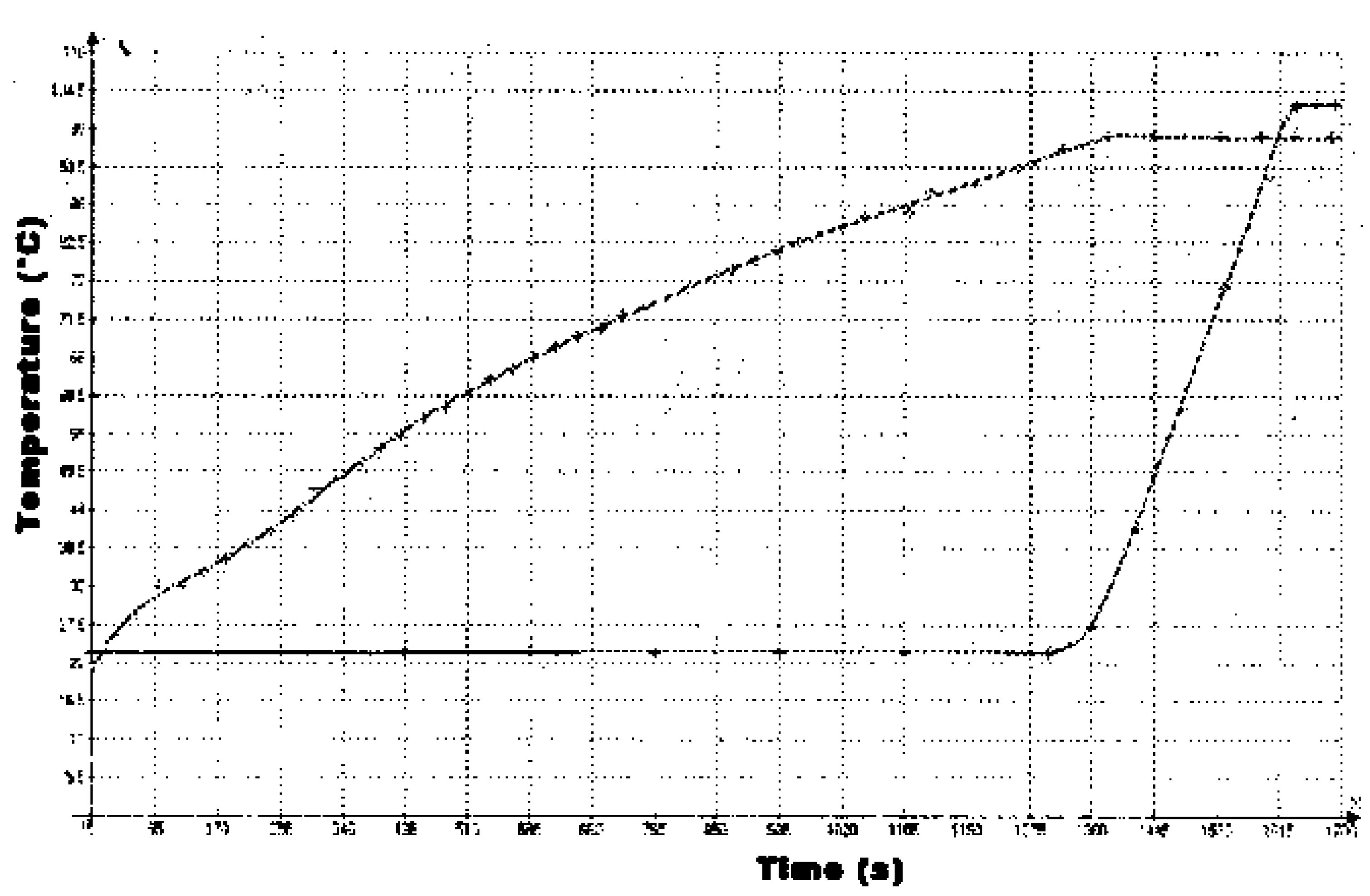
It's important to emphasize that there will always be pure-distillated water in the pressure cooker. The variations in the kinds of solutions are going to be made only in the small recipient.

First, water was injected in the system, to measure its ebullition point, and we started to heat it using an electric heater, positioned under the pressure cooker. When the temperature reached a stable value, we concluded the system was in equilibrium and took our measure. This is the temperature we will have to overcome with the solutions, if we want to prove the energy transference of the problem is possible: 98.43 degrees Celsius.

After obtaining the temperature we'd have to overcome, we started our experiments: The system was connected in a way the vapor would be injected directly into the salty solution, like shown in Fig.1. Using one electric heater, positioned under the pressure cooker, we heated the system. Inside the Pressure Cooker, there were 02,0 liters of distillated water, and in the small recipient, 300,0 milliliters of an aqueous salt saturated solution of Sodium Chloride, with some precipitated salt in the bottom. This precipitated salt had the purpose to saturate the vapor that was going to condensate, maintaining the solution saturated.

As the pure water received heat, its temperature began to rise. When the pure water entered in ebullition, the vapors produced started to raise the pressure, and they were directed to the point where the pressure was smaller: that is, following the plastic tube, to the small container. After reaching the container, the vapor, injected directly into the salty solution, exchanged heat with the solution, and its temperature began to rise too.

While the whole process was going on, measures of the temperatures in both recipients were being taken spaced thirty seconds between two measures. With the data obtained, we built the following graphic, representing Temperature versus Time.



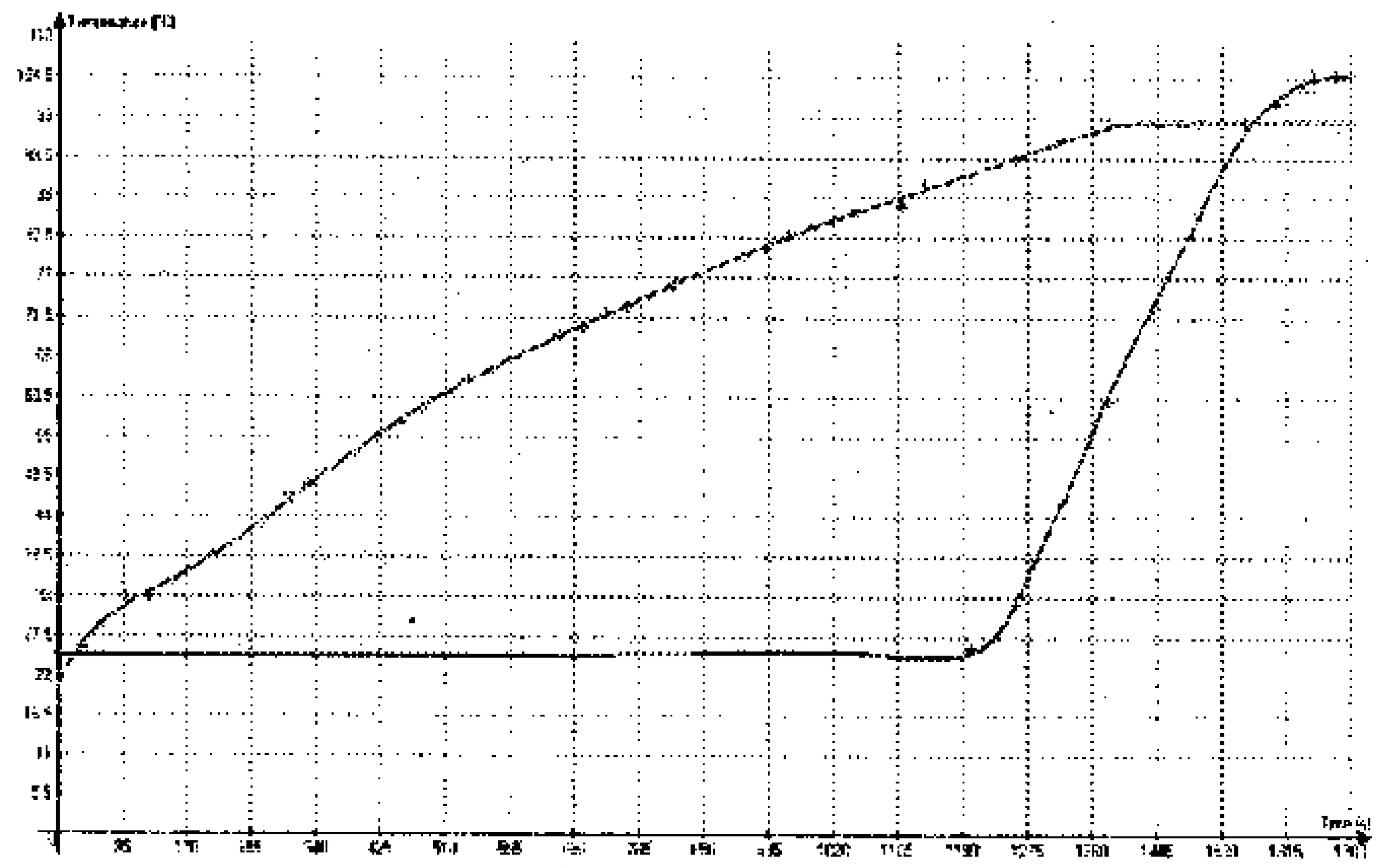
Graph.1 NaCl Solution

The Grey Line represents the pure water's temperature and the Red One represents the salty solution.

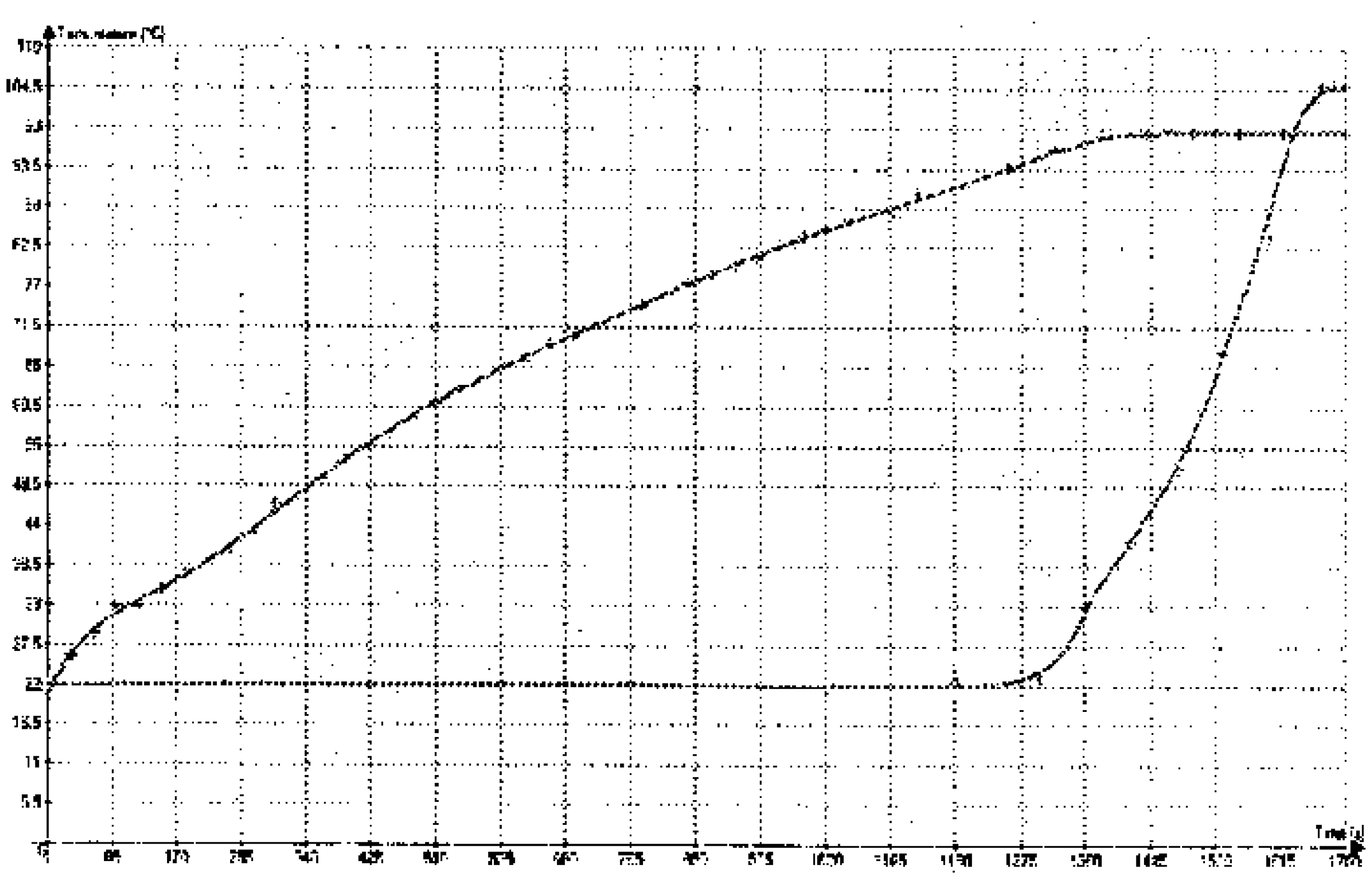
We can clearly see that, after a certain point, the temperature of the water in the pressure cooker remains constant, indicating it reached its ebullition point and that is approximately from this instant that the temperature of the salty solution begins to rise. But, the important thing here is the intersection point between the two lines. In this point, the temperature of the aqueous salt solution surpasses the temperature from the vapor produced in the cooker.

Considering the only source of heat to the solution is the vapor, we can infer the transference of heat mentioned in the problem is indeed possible.

We can also see that, by changing the kind of salt used, like we did in these other experiments (Graph.2; Graph.3), the only difference was quantitative, because the behavior pattern of the lines were the same as before, indicating that a change in the kind of solution does not interfere in the final results, supposing the solution presents the ebullioscopy characteristic.



Graph.2 KCl Solution



Graph.3 Coffee Solution

3 Phenomenon Explanation

When the vapor produced by the water in ebullition makes contact with the salty solution, it begins to transfer energy in the form of heat, until the solution reaches the vapor temperature.

It happens that the saturated solution is filled with dissociated ions of the salt right. So when the steam makes contact with the solution, its molecules interact with these ions and due to the solvents polarity, they become attracted; that is, the steam becomes solvated. When they attach, the ebullition point of the resultant vapor solution rises. But the steam hadn't received any energy during this process, so its temperature remains constant. In some point, the ebullition point of the solvated steam surpasses its actual temperature; and when that happens, it condensates.

When the steam condensates, it releases a lot of latent heat to the medium, because when condensed, it can't sustain that initial energy that the steam had.

This energy is considered Latent Heat to the vapor, because it is in condensation, meaning that its temperature does not change. But to the solution which is absorbing this energy, it is considered Sensitive heat, because it hasn't reached its ebullition point yet. And the newly condensed vapor gets saturated with the precipitated salt, giving continuity to the process. Therefore, the temperature of the solution and of the system rises as a whole, even surpassing the temperature of the water vapor.

4 Conclusions

It was possible to determine the answer of the problem question: Yes, it is possible to heat a salty solution to a temperature greater than the steam which is the only source of heat to the system.

A temperature difference of 6,50 degrees Celsius was reached in the KCl solution, confirming the answer.

The phenomenon can also be observed in any mix that possesses the ebullioscopy characteristic (e.g. Coffee).

The explanation for the phenomenon is the solvation of the steam when it enters in contact with the salty solution and due to the difference in how the two systems "sense" the Heat energy that the vapor releases when in condensation. Meaning Latent and Sensitive Heat.

It was discovered that the phenomenon can be observed with non-salt solutions, and not only with salt solutions.

5. Practical Applications

After finishing our resolution, we tried to find some practical applications for the topics and subjects learned during the study.

We realized that, for having a relatively low mass but carrying a lot of energy, vapor is a great form of energy transportation, and can be widely used in heating processes for high buildings since it is easy to transport it against gravity.

We also found that we can use the phenomenon observed to raise the temperature of certain chemical reactions involving vapors near their ebullition points, increasing its speed and its industrial viability. But in order to do that, the salt can not act as part of the chemical reaction.