10. PROBLEM № 17: OCEAN SOLARIS

10.1. SOLUTION OF CZECH REPUBLIC

Problem № 17: Ocean Solaris

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The problem

A transparent vessel is half-filled with saturated salt water solution and then fresh water is added with caution. A distinct boundary between these liquids is formed. Investigate its behaviour if the lower liquid is heated

Ocean Solaris is very unique problem that is mainly because of two reasons. The first is that the setting of this task is not absolutely clear; second no parameters under which you should work out the solution are mentioned, so you have to choose from wide spectrum of possible solutions.
Setting says: "A transparent vessel is half filled with saturated salt water solution and then fresh water is added with caution. A district boundary between these liquids is formed. Investigate its behaviour if the lower liquid is heated."

You are given a hint how to prepare this experiment but you also have to solve how to put the fresh water on the saturated salt water solution (SSWS) first. And the mainly thing is that you have to work out the entire problem experimentally without any reasonable parameters given by the setting. So I had to do all the work with great diligence in order to do all necessary experiments.

(Used shortcuts: SSWS – saturated salt water solution, DW – distilled water, US – upper solution, LS – lover solution, OSE – Ocean Solaris effect)

I will try to describe my main founds in this article and I would like to mention the real Ocean Solaris effect (OSE) also.

Technique of the experiments

In order to prevent mixing fresh water with SSWS I used paint brush and burette fixed in a holder so tat I could easy module flow and lifting force applied in the brush broke speed of the flowing water that means the boundary was not disturbed. I revised the clearness of the added water by measuring its electro conductivity before and after water addition. Difference between measured data using this procedure was insignificant (average difference was less than 25µs micro siemens, for better measurements was used distilled water). In reality the OSE is not so influenced by the little gap between clearness' of the added water but if the difference is big enough, than the OSE is worse observable. Most of the experiments I did, was made for principal temperature 20ºC (US, LS, temperature of the air) but I also tried to change this so that I used warmer water. But nearly nothing was changed and the higher the principal temperature was, the worse could be the experiment prepared because ions went through the boundary faster.

How the boundary is formed

Boundary between SSWS and DW is like boundary between oil and water but oil doesn't do stable solution with water (standard conditions). Different densities prevent fast mixing so that the boundary appears. After about an hour you can see how the boundary is changed. Its sharpness has disappeared and now you can see SSWS gentle changing in to the upper solution which now contains hundred times more ions. After six hours you get "wary salt water" and here is no boundary any more.

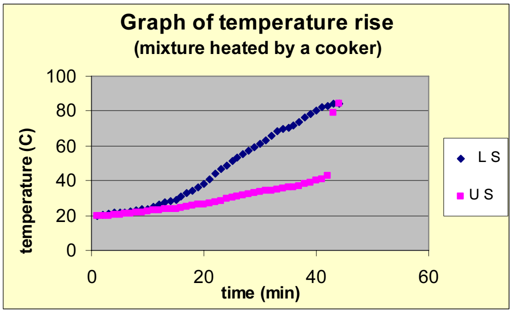
This mixing is caused by oscillating molecules of the water which disturb the boundary and allow more ions get through it. Boundary by itself is not able to prevent anything, which has higher density than the lower solution has, fall down but if you drop something with the right density (smaller than density of LS and bigger than density of US) it seems that this thing stand on the boundary. You can use it for demonstration of changing density during heating but it can influence the effects than.

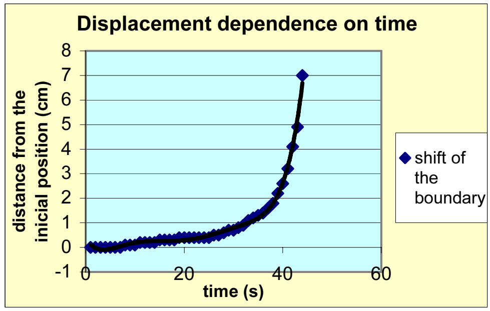
During heating the boundary starts to wave and after some time it disappears. This is the point which nearly all the experiments have common but nothing else. Because of many varieties of the experiments I will mention only two most interesting.

"Insulation" and shift of the boundary

(Main parameters of the experiments: $t_{(SSWS)} = t_{(DW)} = 20°C$, $V_{(SSWS)} = V_{(DW)} = 180ml$ dw = distilled water) When prepared system is heated on a heater you can find really interesting thing if you compare measured temperatures from both solutions. The temperature of the lower (SSWS) liquid is higher and rise faster than the temperature in upper solution. After some time the temperature difference is stabilised on about 40ºC than the lower solution reach about 85ºC (it can even boil! But bubbles destroy the boundary than) and the boundary started to lift fast. In reality the boundary has been lifting since the temperature of the lower solution reach about 60ºC but it hasn't been well observable before. With increasing temperature boundary moves faster and faster (due to the measured data shifting velocity rises exponentially in dependence on time, the power of the heater is constant).

This phenomenon is caused by salinity of the solution which tries to keep the boundary and decreasing density which tries to destroy the boundary (density of the lower solution gets near to the density of the upper solution).

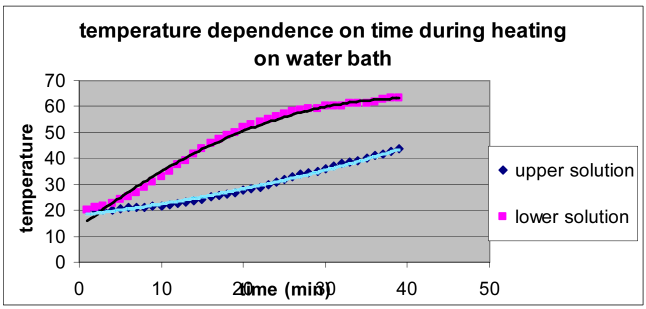




When densities (better say the solutions) are balanced than the only thing which keep them separated is the boundary. But it is not right to say that the densities are the same because density of the US is not constant in whole volume and density of the LS also is not constant in whole volume.

In the graphs you can see data from one of the measurements. Step temperature change in US means that the boundary went around the thermometer.

For heating on the water bath you don't reach high temperatures and the boundary doesn't shift but the temperature difference is also observable.



Main part of the heat added to the system is "store" in the lower solution so that the kinetic energy of the ions is bigger because of that they can go through the boundary faster and salt concentration in US rises. But the waving boundary is still well observable and the US still keeps its lower temperature. You can also see eddy currents in the LS because the added heat causes that the density is not the same in whole volume of the LS and they mixes LS in order to change the density step by step. Sometimes you can see small bubbles, which consist of salt water with different concentration of salt in them than the concentration in the mixture around them is. They appear on the bottom and go up where are stopped by the boundary (they cause bigger waves) and disappear after a while. I didn't study this effect much but I mention it in the part about "real" OSE at the end of this article because I explain OSE by it.

Shifting of the boundary means that molecules of water are transported trough the boundary down to the solution with higher salinity in order to keep the boundary in system and they provide more "space" for the added heat (temperature in US is really much more lover than the LS).

Ocean Solaris

Real Ocean Solaris effect is observable in quite big vessel with volume more than two litters and radius must be bigger than fifteen cm. It is very important how fast you are able to prepare the system for this experiment because is disturbed during the time. The absolutely same volume of the solutions is not necessary but volumes should get near each other. You also need quite large heater ensuring uniform hating of the bottom. The boundary starts to wave at first quite gently but than the waves become bigger and bigger and when they are big enough the boundary is destroyed and this effect is really gorgeous. I didn't overwhelmingly prove that the waving was caused by bubbles formed by less concentrated salt water solution but style of the destruction of the boundary indicated that something like huge bubbles arising at the bottom could really made this effect.

I think this is possible because the larger bottom provide more space and small bubbles which at first stay at the bottom can interweave and make themselves in one really huge bubble which still stay at the bottom until its density is so low that this bubble can easy break away from the bottom and it can hit the boundary with a great bump which is able to smash it. The main problem is the detection of these bubbles because it is hard to observe the smaller ones and I except densities aren't so different from the rest of the solution so it is really hard to observe them.

The second reason why I thing this effect is caused by bubbles is that I didn't realise eddy currents in the lower solution as it was usual in the smaller vessels. Eddy currents mix the lower solution because temperature transport is not ideal so temperature at the bottom and near the boundary could be different. If the bottom is very small or quite large eddy currents don't appear or appear after longer time. If there are not eddy currents in (heated) LS than is more probable you can observe the "bubbles". If there are not eddy currents than there have to be bubbles but you can't actually see them, the only thing you can observe is waving of the boundary and its destruction.

In fine I would like to say, that OSE how it was described in official solution of this task, appears to be less important if it is compared with the other effects which was observed during solving this task.