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Some Reflections on the Evaporation and Condensation Phenomena

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Abstract: *We examine the phenomena of evaporation and condensation. The main argument of our research is related to the event of formation of boundary layers in nature. The research is a proposal for a model describing some phenomena based on current but not fully proved knowledge. We claim that evaporation and condensation are the most efficient ways of transport of heat and therefore could be described in some aspects by a Carnot cycle.*

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I. Main Part

Following some recent work on shells and boundary layers [Koutandos 2012, Koutandos 2013] we would like to pursue our research to the field of evaporation, condensation and boiling. Now, although boiling is a first order phase transition, in some aspects which we will describe, resembles changes of phase in other areas of physics such as is superfluidity and superconductivity.

Due to surface tension as we are well aware of, the liquid once evaporated takes the form of a spherical droplet. The sphere is the shape with minimum area and this way the gained free energy due to surface tension is minimized. Now what could be said is that there is a fact less mentioned in textbooks. Although the tendency in nature is for minimization of the free energy during evaporation a surface layer is being formed which elevates the free energy of the system. This layer has to be therefore as narrow as possible. The estimates are for a few nanometers to a few micro meters.

The layer being formed between the main part of the liquid and the main part of the gas-vapor system has been mentioned to be turbulent [Collinet et al] . The reason for this is that two competing factors drive the flow of the gas or vapors. Firstly we have a gradient of the surface tension. The Marangoni effect forces the particles from areas of high surface tension to areas of low surface tension. Then we have a gradient of temperature. Of course we have movement of highly energetic particles from areas of high temperature to areas of low temperature. The turbulence could also be attributed to the combination of the diffusive and thermal transport properties of the evaporating layer.

The phenomenon of interfacial thermal resistance is well established by Kapitza and can be accessed on the internet. This phenomenon describes the event mentioned by Koutandos [Koutandos 2012] of formation of a shell with high thermal resistance within the evaporating layer. Therefore during the process of evaporation or boiling which is a more violent process the droplets in the first place don’t interchange much energy with the gas above. This is due to be expected at least in boiling coming from the volatility of the transition. So therefore the process in the fist few nanometers or micrometers could be considered adiabatic.

The droplets bursting from the liquid-gas interface naturally tend to grow and there are a few good reasons to mention for this. What appears immediately as an evident observation is that the layer is of the order of a few or one droplet as measured within the bulk of the gas-vapor system. There is a more perplex reason for why this happens also. The drops at he beginning of their existence inherit the turbulent boundary layer and a layer of pressure jump is formed around them. An easy way to understand is this: As the liquid is evaporating away from the droplet, from Newton’s law of action reaction we have an oppositely acting pressure. This pressure jump has a counterpart from Laplace’s formula:

$$\frac{\gamma}{R} = \Delta P \quad (1)$$

On the above formula (1) gamma is the surface tension and R the curvature.

We believe that the surround layer of the droplet is turbulent for as long as the droplet grows. In fact in literature [Shreshefsky et al 1936] it has been long mentioned that the rate of growth of the volume of the droplet is proportional to a difference in pressure:

$$\frac{dm}{dt} = \rho \frac{dV}{dt} = K\Delta P \quad (2)$$

Indeed then through the boundary layer we have an adiabatic process during which the droplets increase in size and thus this is an adiabatic expansion if we choose to consider the vapor system as a different system from the gas system. If we actually have a turbulent layer surrounding the droplet and a pressure jump then it has to be born in mind that a spherical layer of turbulence will act as a point vortex or at least some kind of spherical one due to symmetry. The droplets naturally the attract each other as do areas of negative pressure if we prefer to call as such the sub pressure.

If it so happens that we have an adiabatic expansion taking place through the boundary layer the rest of the picture appears. There is also the isothermal event of formation of the droplets at the beginning of the layer during which heat is absorbed. The reverse of the evaporation is condensation and this completes a Carnot cycle. The phenomenon is a Carnot cycle for the vapor gas because the other gas(airs) completes the reverse Carnot cycle and thus the process is the most efficient leading to minimization of the free energy.

II. Conclusions

We have studied the phenomena of evaporation and condensation and have reached the conclusion that the process might resemble a Carnot cycle. We mention the simple fact that during the early research of Carnot it is exactly because steam has similar behavior regarding the adiabatic expansion with an ideal gas that his research was fruitful.

The coefficient of efficiency appearing in Carnot cycle is:

$$\eta = \frac{\Delta T}{T} \quad (3)$$

This coefficient has been found to appear in the second order expansion of the Gibbs free energy by the author [Koutandos 2013].

Finally we refer to a book on superconductivity [Tinkham] for the reader to find that the first coefficient of the free energy expansion in a Landau-Ginzburg formula is proportional to a difference in temperature between the critical state and the normal. The reader there may also find big resemblances of the superfluid or superconducting phenomenon with this one described in this article. The formation of a vortex lattice is the least that could be given as an example.

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