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Designing Cloud Chamber for Simulate the Microphysics Processes in the Formation of Ice Crystals

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ABSTRACT

The simulate microphysical processes in the atmosphere, a cloud chamber, which behaves as the atmosphere, has been designed and fabricated in order to be used to execute several atmospheric experiments. These experiments allow a better understanding of clear visual cloud formation. The executed temperature and saturated pressure experiments clarify the basic mechanisms of the ice crystals nucleation, which in contrast, represent the core of the cloud microphysics. The cloud chamber can represent an isolated environment that deals with a certain volume of pure air and contains certain nucleation particles or ice nuclei. The temperature range in such a chamber is similar to that found at the mid-latitudes between the surface of the earth and the top of the troposphere. Thus, it is possible to simulate clouds of the type of Cirrostratus at the bottom of the chamber. It has been designed with dimensions of 22×22×59 cm3 and made of 3mm in thickness copper with a purity of 99.9%, and thermal conductivity of 401 W/m.°K.

KEYWORDS: Cloud chamber, microphysics of cloud, ice crystals, dry ice.

الخلاصة

لمحاكاة العمليات الفيزيائية الدقيقة في الغلاف الجوي، تم تصميم غرفة السحاب، التي تتشابه فيزيائيا مع ما يحدث في الغلاف الجوي، وتصنيعها من أجل استخدامها في تنفيذ العديد من تجارب الغلاف الجوي. في المقابل، تتيح هذه التجارب فهمًا أفضل لتشكيل السحب المرئية الواضحة. توضح تجارب درجة الحرارة والضغط المشبع التي تم إجراؤها الآليات الأساسية لتنوى بلورات الجليد، والتي تمثل في المقابل اساس الفيزياء الدقيقة للسحب. تمثل الحجرة السحابية بيئة معزولة تم استخدامها للتعامل مع حجم معين من الهواء النقي أو تحتوي على جزيئات نواة معينة أو نوى جليدية. نطاق درجة الحرارة داخل حجرة السحب مشابه لتلك الموجودة في خطوط العرض الوسطى بين سطح الأرض وقمة التروبوسفير. وبالتالي، من الممكن محاكاة السحب من نوع سروستراتوس في أسفل الغرفة. الغرفة السحابية مصممة بأبعاد ٢٢×٢٢×٥٩ سم^{٣} وتم تصنيعه من النحاس بسمك ٣ مم وبنقاوة ٩٩,٩٪، وموصلية حرارية ٤٠١ وات/م.ك.

INTRODUCTION

Cloud physics, as a branch of atmospheric physics, is concerned with the study of the physical processes of clouds formation. The formation of ice crystals in the atmosphere, which considered as one of these processes, has studied for many years with increasing attention to the physical and chemical nature of the atmosphere due to the importance of the experimental atmospheric meteorology and pollution [1]. understand these processes, the best relationship between suspended particles, water, clouds, temperature and radiation was emphasized. It is also clear that the general concept in the basics of cloud science involves knowing the composition of clouds and the evolution of precipitation phases. Two different methods are responsible for the development of clouds and precipitation and explain the formation of the atmospheric distillation and growth and their impact on the surrounding [2].

First method, air masses essentially saturated, that is, they contain relative humidity close to 100%. These can mostly be obtained through vertical movements of the air in the free clouds. These vertical movements have horizontal extensions within a range of 10 meters to hundreds of kilometers depending on how they produced and the vertical velocity ranges from a few centimeters per second to tens of meters per second depending on how they formed. Vertical movements are important for the formation of clouds, and they play an important role in determining the characteristics and amount of precipitation [3].

Second method is on a much smaller scale than the 1st. One if the size of this measure compared to the dimensions of the cloud and precipitation particles. The objective of studying cloud physics is to explain the conditions under which a single droplet can grow in a vapor state until it becomes visible in size and then interacts with other cloud particles to form precipitation [4]. The design of the continuous cloud chamber enables us to conduct many practical experiments in the field of cloud physics to enhance the results of the computer simulation programs. The difficulty of the subject lies in how to control and monitor the atmosphere of the troposphere where most of the processes of warm and cold clouds occur. The average temperature ranges from +15 °C near the Earth's surface to -58 °C near the top of the troposphere at a height of 12 km [1]. For this wide range, the cloud chamber is designed to simulate the conditions of this layer, which is similar to the vertical air temperature range in the mid-latitudes between the Earth's surface and the troposphere. This allows us to study how clouds and crystals evolved from the formation of cloud droplets.

Objectives of the cloud chamber's design

1. Monitoring the physical processes of the mixed phases and cold clouds on the nucleation of the ice.
2. Consolidation of the basic concepts of the ice nucleation mechanisms which are the main topics of cloud physics.
3. Executing several experiments under low temperatures in addition to form different shapes of ice nuclei.
4. Enhancing the scientific research of cloud formation and ice crystals nucleation under lab conditions similar to that of the atmosphere.

The design of the cloud chamber allows the temperature to reach -60 °C due to the used dry ice, which has a temperature of -78 °C [5].

Composition of air

The air is a mixture of permanent gases with different percentages and different minutes of solid particles and liquids. Nitrogen and oxygen constitute about 78% and 21% respectively of the total volume of permanent air gases. The remaining 15% consist mainly of argon with a small amount of neon, helium and other gases. The composition of the air is clearly similar over all parts of the globe and within a layer extending from the surface of the earth to a height of about 90 km with a stabile ratio between the different components of the atmosphere [1]. In addition to the permanent group of gases, the ratio of other gases varies in time and place. Water vapor, carbon dioxide and ozone are the most valuable members of this group. This latter group of gases has a significant impact on heat transfer processes, while water vapor plays a central role in atmospheric thermodynamics. The minutes of solid particles and liquids suspended in the atmosphere are called aerosols or plankton. Common examples of this plankton are the minutes of normal dust, pollen, and water drops, which form the clouds. Thermodynamics concerns about the gaseous part of the atmosphere, while certain groups of solid plankton called as hydrophilic nuclei are essential in the process of condensation of water in the atmosphere. In meteorology, air is a mixture of two ideal gases, dry air and water vapor. This mixture was called wet air. The thermodynamic characteristics of wet air are determined by uniformity of both dry air and the vapor on aerosols [2].

In 1880 the Scottish engineer (Aitkin) produced small clouds of water using a technique which had been proposed in France by Mascart and Coulier, where it was ascertained that how could he formed clouds in his first experiment (Aitken's cloud) by using a sample of water vapor in a large glass container. If the chamber contains normal air, the cloud will be formed. But if it contains pure air, the cloud can only be formed when the moisture reaches 400%. Since the cloud is formed only if the air contains aerosols, then it will be formed only, when the water vapor condenses into water droplets around the particles [6].

Cloud formation in nature

The water evaporates when heated by sunlight from the; oceans, rivers and lakes that acquire enough energy to be released from the surface of the water and spread in the air in the form of water vapor molecules. Some of these molecules raise higher in the atmosphere where the air is cooler and the less is temperature. The water molecules lose some of its energy and condense to form clouds. In an attempt to simulate the natural clouds, John Aitken changed his experiment in which he put a little water in the bottom of a large glass container and waited until the air inside the container is filled with water molecules. By expanding the container, the trapped air was cooled, due to the volume increase and pressure decrease. This, in turn, led to condense the water vapor on to the aerosols which were suspended in the air and finally, forming the cloud. While in pure air no cloud was formed although the air was cold but without the suspended particles, the moisture needed to be sufficient enough for the cloud to be formed. Aitken's experiments showed that expansion can produce clouds in the air that contains condensation nuclei (dust, smoke, etc.) with a little aerosol, while the cloud can be formed in a fully dusty air as shown in Figure 1 [3].

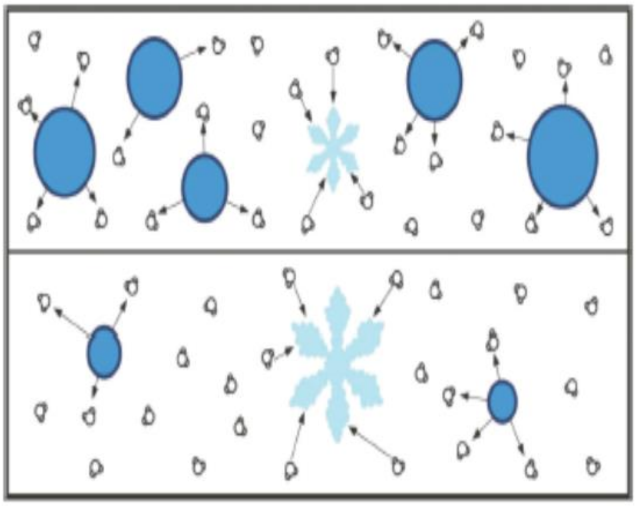

Figure 1. Scheme of the effect of ice nuclei from various sources of aerosol possible on medium-level and hydrofluoric clouds [5].

Atmospheric aerosol

The air contains a certain amount of microscopic particles and molecules and sometimes, contains fairly large particles, especially those that are made up of fibers, dust and other light objects such as pollen. Most of these particles are solids or small liquid droplets and they come from multiple sources, such as plants, volcanoes, sea droplets and desert dust storms.

Industrial emissions in Figure 2 and other sources produce floating particles. These molecules are called fine aerosols (i.e., nanoparticles), which, some of them, can act as centers for water droplets called as cloud condensation nuclei or ice crystals [7,8]. Depending on their composition and size, these nuclei have various degrees of activity and their quantity also vary.

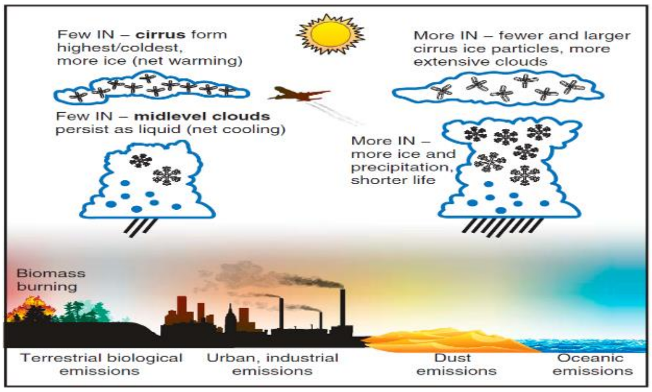

Figure 2. Schematic diagram of the growth of ice crystals at the expense of water droplets [9].

Pressure of saturated steam over water

At temperatures below 0 °C the air may become saturated either with regard to ice or in relation to water. Equations 1 and 2 can be used to calculate the saturated vapour pressure above the ice and water as a function of temperature [5].

$$p_{ice} = exp\,(9.550426 - \frac{5723.265}{T} + 3.53068 * ln\,ln\,(T) - 0.00728332 * T) \quad (1)$$

when; T > 110 °K

$$p_{water} \approx exp\,(45.842763 - \frac{6763.22}{T} - 4.21 * ln\,ln\,(T) + 0.000367 * T + tanh\,tanh\,\{0.0415 * (T - 218.8)\} * \left(53.878 - \frac{1331.22}{T} - 9.44523 * ln\,ln\,(T) + 0.014025 * T\right)) \quad (2)$$

when; 123 < T < 332 °K

As temperature below 0 °C, the vapor pressure above the ice is less than that above water. Thus, if the cloud drops and the ice crystals occur together in the same cloud (the mixed phase of the clouds), the ice crystals will grow at the expense of water droplets, where all drops of the cloud disappear and the crystals become larger and begin to fall [6, 10].

Ice nucleation mechanisms

Ice nucleation occurs either homogenously at temperatures below -38 °C (where cirrus clouds are formed) or heterogeneous at temperatures below 0 °C at the surface of the aerosol particles in the air [2, 3].

Non homogeneous nucleation paths

Four different mechanisms of heterogeneous ice nuclei (immersion, sedimentation, docking, and condensation) are shown in Figure 3 [10, 11].

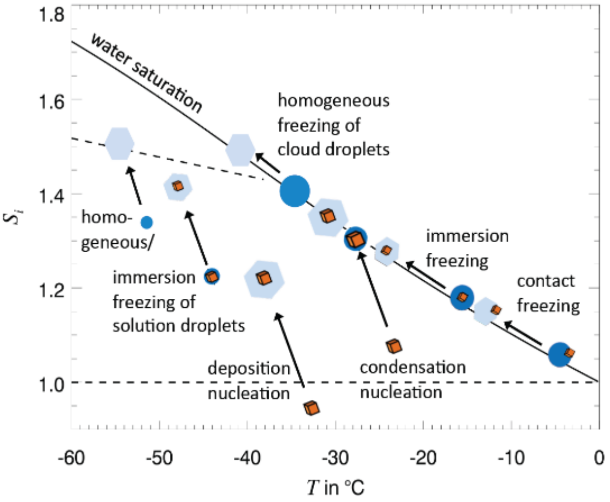

Figure 3. Air tracks of temperature and saturation of ice to expel rising air which leads to formation of ice in different nucleation.

Schaeffer cloud chamber

The base of the chamber is cooled by dry ice packed around it. The upper plate, where the temperature is balanced between the environment temperature and the cloud chamber, is exposed to a little water by a sponge fixed to the upper plate. A deeply cooled area is created by the copper box installed perpendicularly on the base. The whole chamber is installed in a box made of thermally insulating material where the chamber is placed in a box of insulating material containing dry ice. The equilibrium conditions are reached after one hour and the progress of the cooling is monitored by the thermocouples. Figure 4 illustrates the whole prepared chamber to start the experiment [5, 12]. Since the cold air is heavier than the warm air, it stays in the chamber even when the upper part is open.

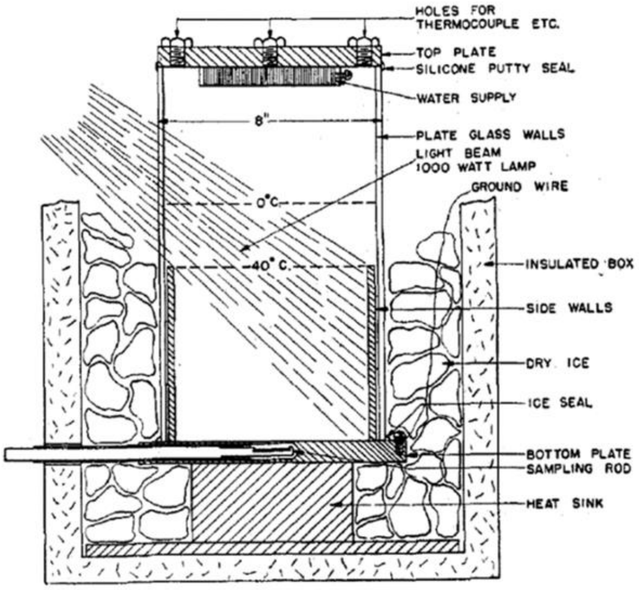

Figure 4. Schematic diagram of the whole prepared cloud chamber.

The greater the temperature difference between the air in the chamber and the surrounding, the air inside the chamber will be more stable [13]. The lighting of the chamber is supplied from a source of parallel radiation. It is better to direct the radiation at an angle of 45° to illuminate a larger cross section of cold air. A nearby light source will heat the chamber's window. As the chamber begins to cool, an attempt to form a cloud begins. Wet sponge supplies the chamber with the required humidity from time to time and the temperature at which the cloud forms is the degree of dew [14]. The air inside the chamber at a certain temperature is saturated with water vapor, then any additional added moisture condenses over the aerosol particles that were invisible. At normal weather conditions from 100 to 1000 condensed active nuclei per cubic centimeter of air, the cloud droplets formed on such cores grow rapidly to a diameter of about 10-15 micrometers. They look much larger in the beam of light because they diffuse light efficiently [14, 15].

There are many experiments that can be carried out by the designed cloud chamber. To mention some but not all:

1. Determine the saturated vapor pressure above the ice and water depending on the temperature.

2. Determine the amount of water in 1 m^3 of saturated air at different temperatures.
3. Formation of clouds at temperatures below
-2 °C.
4. Determine the vertical distribution of the temperatures along the cloud chamber.
5. Recording the activities at the conditions of low temperature between -60 and -70 °C.

RESULTS AND DISCUSSION

The current experiment has enabled to record the vertical temperatures along the cloud chamber by the thermocouples the chamber reached the required temperature range for forming. Figure 5 illustrates how to visualize this case study. Figure 6 shows the vertical distribution of the temperatures along the cloud chamber. The Figure 7 shows the vertical distribution of the temperatures along the troposphere layer, in which the distribution in the chamber matches it. The designed cloud chamber showed an excellent performance during operation. The recorded temperatures along the interior height of the chamber almost matched the distribution at the different heights of the troposphere layer. Figures 8, 9, 10, and 11 show the pictures for the processes of photographical the formation of the ice crystal inside the designed cloud chamber under test.

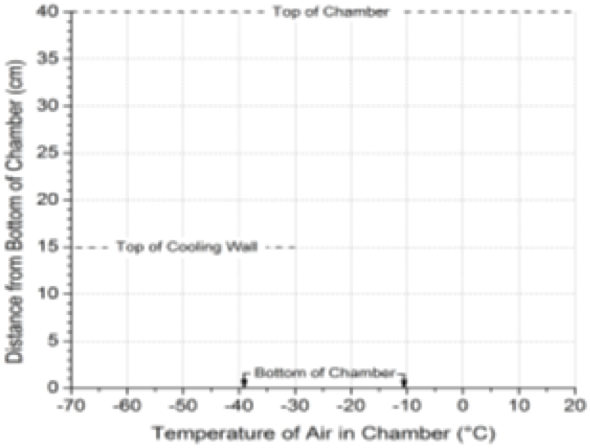

Figure 5. Temperature distribution inside the cloud chamber.

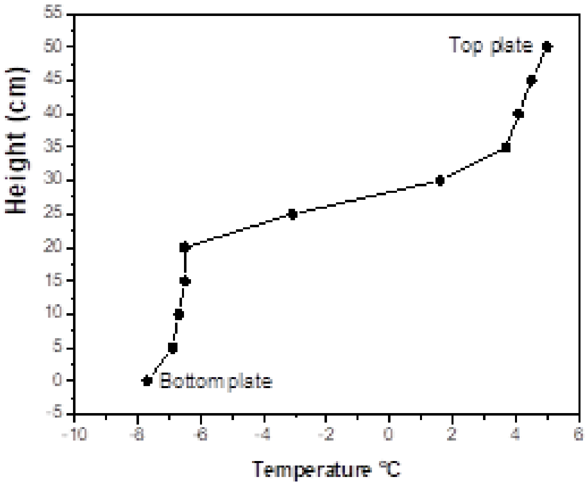

Figure 6. Vertical distribution of the temperatures inside the cloud chamber.

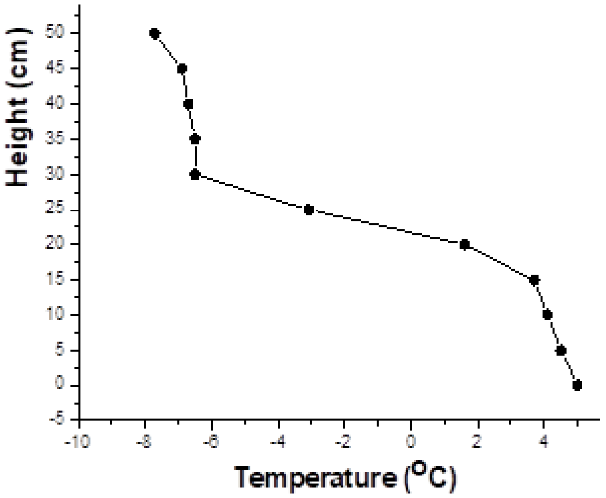

Figure 7. The vertical distribution of the temperatures along the troposphere layer.

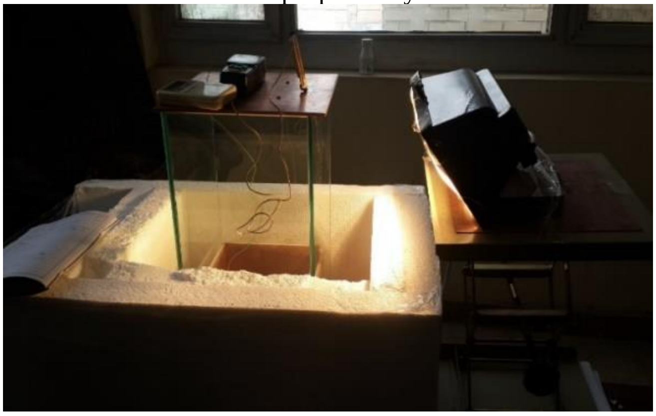

Figure 8. The designed cloud chamber during the test.

Figure 9. The ice crystals nucleation.

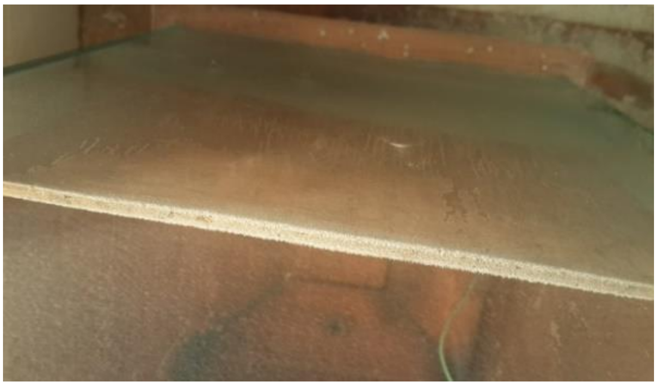

Figure 10. Water crystallization.

Figure 11. Survival of the ice crystals at the bottom of the chamber.

CONCLUSIONS

1. The amount of dry ice has a noticeable effect on the temperature inside the cloud chamber where the temperature was very low temperature of -78 °C.
2. The simulation temperatures inside the cloud chamber are similar to that at the mid-latitudes.
3. The atmosphere inside the cloud chamber was appropriate for the formation of clouds since it achieved the required humidity, vaporization, and low temperature.
4. Humidity-saturated air directly converted to ice crystals even before running the lamp due to the achieved very low temperatures.
5. The vast difference in temperature between the surface of the earth and the top of the cloud.

Disclosure and Conflict of Interest: The authors declare that they have no conflicts of interest.

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