Using Vapor Generation Equipment to Create Artificial Rain: The Design and Function of a New System

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Abstract: The incidence of water shortage events – including drought, forest fire, and desertification – is rapidly increasing due to global warming. This paper shows the principles and the practical application of a new artificial rain system that would help prevent these types of harmful water shortage events. The proposed artificial rain system is composed of solar-powered vapor generation equipment that floats on a large body of water. From this water, vapor is generated by means of solar energy. This vapor is transformed into clouds. These clouds are transported to an area experiencing water shortage, and these clouds provide rain to the target area. The proposed artificial rain system can be designed to provide a specific amount of rain, to be applied at a pre-determined time, to a specified area. This equipment is operated by solar power, so does not produce any CO_2 emissions. The detailed design example shown in this paper demonstrates that a vapor generation equipment group 1,080km square in area can make 1,200 kg of vapor per square meter per one year, and provide precipitation for an agricultural area 9,720 km square. The advantages and disadvantages of this system are considered. The estimated cost to produce one kilogramme of precipitation water by the proposed artificial rain system is about 0.002USD.

Keywords: Water shortage, global warming, solar power, CO_2 emissions, Wind Generation Equipment.

1. INTRODUCTION

The Earth is getting warmer and the occurrences of extreme weather events are increasing. The Intergovernmental Panel on Climate Change (IPCC) has shown that the average temperature of the Earth is rising [1], and that an observed increase in water shortage events, such as drought, forest fire and desertification is due to global warming [2]. Fresh water is necessary for human life, agriculture and industry. Technologies such as dams, irrigation canals and artificial rain have been developed and applied to provide fresh water.

Artificial rain is a kind of intentional weather modification, or an attempt to change the amount or type of precipitation that falls from clouds. Existing artificial rain systems disperse substances such as dry ice and silver iodide into the air that serve as cloud condensation or ice nuclei [3].

Vincent J Schaefer performed the first artificial rain experiment, artificially inducing snow by sprinkling dry ice in clouds in 1946 [4]. The first artificial rain attempt was successful in making artificial snow. More recently, an 8.8 million USD pilot project in the United States of America has been conducted to examine whether seeding silver iodide in clouds produces a measurable increase in snowfall over Wyoming's Medicine Bow, Sierra Madre, and Wind River mountain ranges began in January 2006 [5]. In Australia, cloud-seeding between 1960 and 2005 over a hydroelectric catchment (target) area located in central Tasmania was performed. The results indicate that increases in monthly precipitation are observed within the target area during the period of cloud-seeding activity [6].

Existing artificial rain systems employ a method of dispersing into the air substances such as dry ice that serve as cloud condensation. This can facilitate precipitation from existing clouds in the area where the precipitation is required. Whether the existing artificial rain system succeeds or not depends on the presence of clouds or vapor. If no clouds are present, the system is not able to produce rain. Thus the amount, timing and location for precipitation cannot be controlled by the existing system.

In nature condition, vapor generates on a sea surface and is transformed into clouds. The evaporation rate on the sea surface depends on latitude of the sea location, temperatures of air and the sea surface, humidity, wind, sunlight and so on. The evaporation rate was studied by some organizations. For example, Holland J. Z. reported that the Barbados Oceanographic and Meteorological Experiment (BOMEX) was a multi-agency national research project to provide data on the sea-air flux of energy [7]. The observational period of the BOMEX Sea-Air Interaction Program was 1 May through 2 July, 1969. The observations were concentrated on a 500km by 500km square lying to the east of Barbados (The square area is at latitude 12 to 16 degrees north, and longitude 52 to 60 degrees west). BOMEX shows that the

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evaporation rate on the sea surface is measured to be 5-6 mm/day. Therefore, if nature vapor is collected and timely transferred to a region which requires rain, the existing system may be useful. But so far no system for collecting vapor is proposed.

A new artificial rain system composed of vapor generation equipment has been previously proposed and advanced [8]. The new artificial rain system makes vapor of sea or lake water. The present paper describes in detail how this proposed artificial rain system would be designed. Chapter 2 provides an overview of the proposed artificial rain system. Chapter 3 shows a detailed design example and how the system would function. Chapter 4 provides cost estimates for this system. Chapter 5 and Chapter 6 offer future considerations and a paper conclusion, respectively.

2. PROPOSED ARTIFICIAL RAIN SYSTEM

A new artificial rain system, which has been designed to allow for the control of the specific amount, timing and area for an application of artificial rain, was proposed. The proposed artificial rain system is composed of main four functions: vapor generation, wind generation, weather simulation, and precipitation operations, as shown in Table **1**.

Table 1: Main Function of the proposed artificial rain system

Main Functions	Component
Vapor generation function	Vapor Generation Equipment
Wind generation function	Wind Generation Equipment (heater & cooler)
Weather simulation function	A weather simulator
Precipitation operation function	A computer, rain gauges and existing seeding system

The vapor generation function is realized by a group of Vapor Generation Equipment (VGE) as described in section 2.1. The wind generation function is realized by Wind Generation Equipment (WGE) as described in section 2.2. The weather simulation function is a computer-based weather simulator that can provide weather forecasts for a specific area. The weather simulator is not designed to be completely accurate, but rather to provide a level of probability that would render the system effective. The precipitation operation function is composed of a computer with a telecommunication system, rain gauges set up in areas where artificial rain is to be applied, and an existing cloud seeding system. This function allows for the planning and control of the application of artificial rain – including the amount of rain to be applied, the time of application, and in a specified area. This function uses the other three functions as described in Chapter 3.

2.1. Vapor Generation Equipment

The Vapor Generation Equipment (VGE), as shown in Figure **1a**, is composed of floating material (F) made of a series of three vinyl tubes, and a cotton sheet (S), which by using capillary action continuously creates a layer or film of water on the floating material (F). As the water on the cotton sheet S has a thickness of about 1 millimeter, and its amount is very small, it is heated and changed to vapor using solar energy as shown in Figure **1b**. Figure **1b** shows a case that the VGE is set up in a tropical region at low latitude, there is 1kg sea water per one meter square of the water film, and sunlight energy on the water film is about 1000W/m^2. Sunlight energy is used for making 1kg vapor of sea water per one hour. Lalent energy is about 630W hour for making 1kg vapor. The remains of sunlight energy (370W hour) per one meter square per hour is used to heat vapor and circumstance air.

Each of the three vinyl tubes has an “air gateway” for the intake and release of air, run by an air pump, as shown in Figure **2**. When the three vinyl tubes are filled with air, the floating material F floats on the surface of the sea. As the sheet S will have salt on its surface, after about one hour, the sheet’s capillary action is blocked. Therefore, it is necessary to remove salt on the sheet S. When air is released from the three vinyl tubes, the floating material F sinks in the sea. After about one minute, the salt on the sheet S has been dissolved in the sea. Air is re-taken into the three vinyl tubes, allowing the floating material F to float again. This operation is repeated roughly once an hour. Thus, the VGE can continuously make vapor without salt disturbance. The VGE group has three separate air tubes. In the case that one of the three tubes is non-functioning (e.g., punctured by fish), the system is able to operate for a short time without any significant impact on the system’s functionality. However, if two of the tubes are non-functioning, one or both tubes should be repaired as soon as possible. The tubes can be repaired by applying a patch on the punctured part of the tube.

When a storm approaches the area of the sea where the VGE group is floating, the equipment must be submerged to avoid damage caused by large

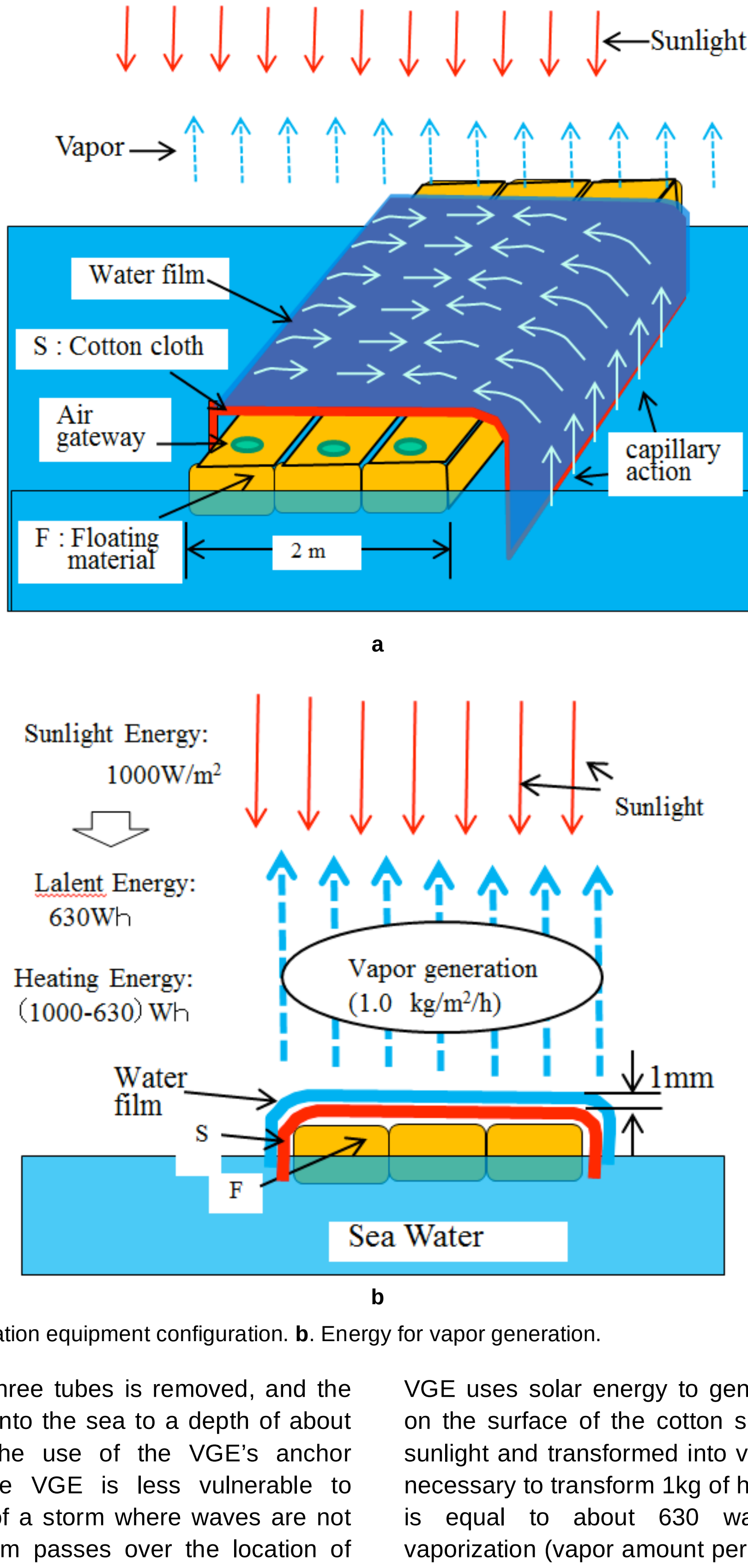

Figure 1: a. Vapor generation equipment configuration. **b**. Energy for vapor generation.

waves. The air in all three tubes is removed, and the tubes are submerged into the sea to a depth of about 50 meters, through the use of the VGE's anchor system. Note that the VGE is less vulnerable to damage in the event of a storm where waves are not strong. When the storm passes over the location of where the tubes are floating, the three tubes of the VGE are re-filled with air and they float again on the surface of the sea.

VGE uses solar energy to generate vapor. The water on the surface of the cotton sheet S is heated bythe sunlight and transformed into vapor. The latent energy necessary to transform 1kg of hot water to 1kg of vapor is equal to about 630 watt-hour. The rate of vaporization (vapor amount per meter square per hour) depends on atmospheric pressure, temperature, humidity and wind.

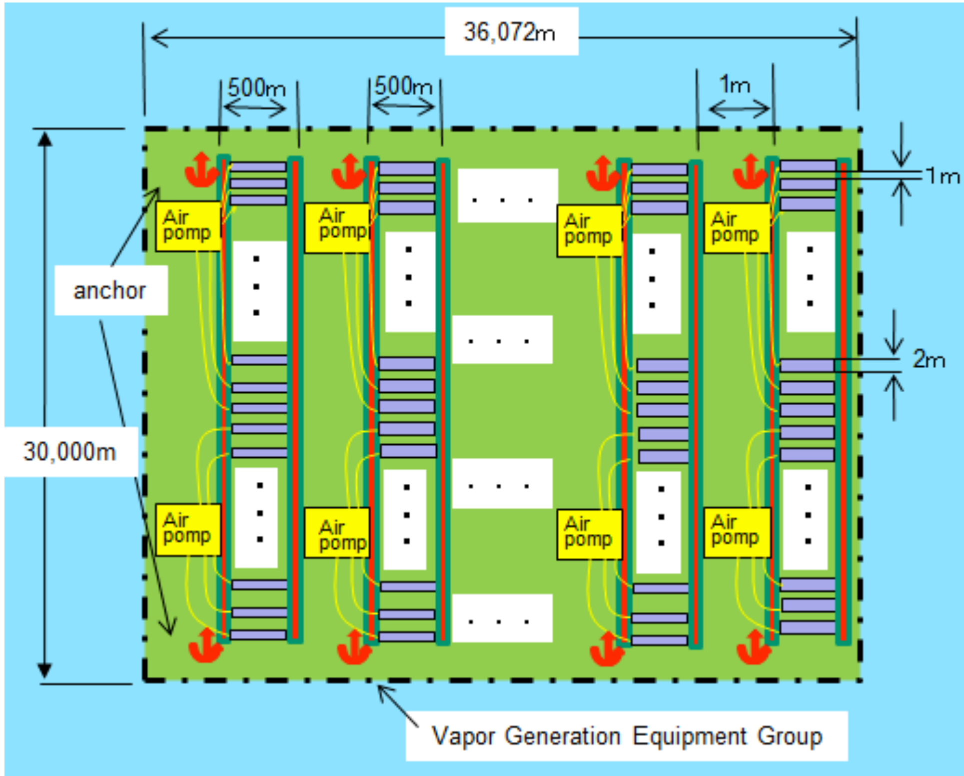

Figure 2: Setting image of a vapor generation equipment group.

In Fukuoka prefecture of Japan (at lat. 30 degree north), a small-scale experiment was conducted by the author over 20 days in August 2008. Two small pools for the experiment are filled with sea water. One poll is installed with VGE, and VGE covers all of the water surface of the pool. The other is installed without VGE. The experiment showed that about 0.8 kg of water in the pool with VGE can be transformed into vapor per meter square per hour under the conditions of temperature between 29 and 37 degrees centigrade and humidity between 31 to 65 percent, and sunlight power is about 800W. About 0.8kg vapor is made by only VGE. On the other hand, about 0.4 kg of water in the other pool without VGE can be transformed into vapor per meter square per hour. It is clear that VGE makes vapor efficiently. The maximum power of solar energy in Fukuoka prefecture of Japan is about 800 watt per one meter square. This experiment is an example, with its results dependent on the location and condition of the experiment.

An example of a VGE group, which includes a large scale VGE, is shown in Figure **2**. The total amount of vapor which is made by the VGE group depends on the size of the VGE group. Setting timing of the VGE group is nearly the same timing to produce artificial rain, and a setting location of the VGE group is a location in the sea near to an artificial rain region by taking account of WGE effect. As the VGE group has anchors, the sea current cannot cause the VGE group to drift away. The VGE group is set up in the sea and it is about 100 meters in depth. In this example, the length of the VGE group is about 36,000 m, and consists of 720,000 sets of individual VGE. Each individual VGE is 2 m in width and 500m in length. Each VGE is separated by a space of 1 m. This configuration results in a VGE group having 0.67 meter square of average VGE surface area per meter square. The size of the VGE group is about 36,000 × 30,000 m square. If the VGE group area is controlled daily, the amount of rain can be controlled by the area of the VGE group daily.

In most cases, a hot and dry region that could benefit from artificial rain has a lot of solar power. Therefore, in this paper it is assumed that the VGE can make 1 kg of vapor in one meter square per hour. The VGE group, as shown in Figure **2**, has a total area of about 1,080 kilometer square, and could make about 4.32×10^9 kg of vapor per day (6 hours). This vapor can make clouds which change to about 4.32×10^9 kg of precipitation. Depending on the placement and timing of the VGE group setting, the area, amount, and timing of artificial rain could be controlled.

Figure **3** shows the proposed artificial rain system and an image of vapor movement. When wind speed is

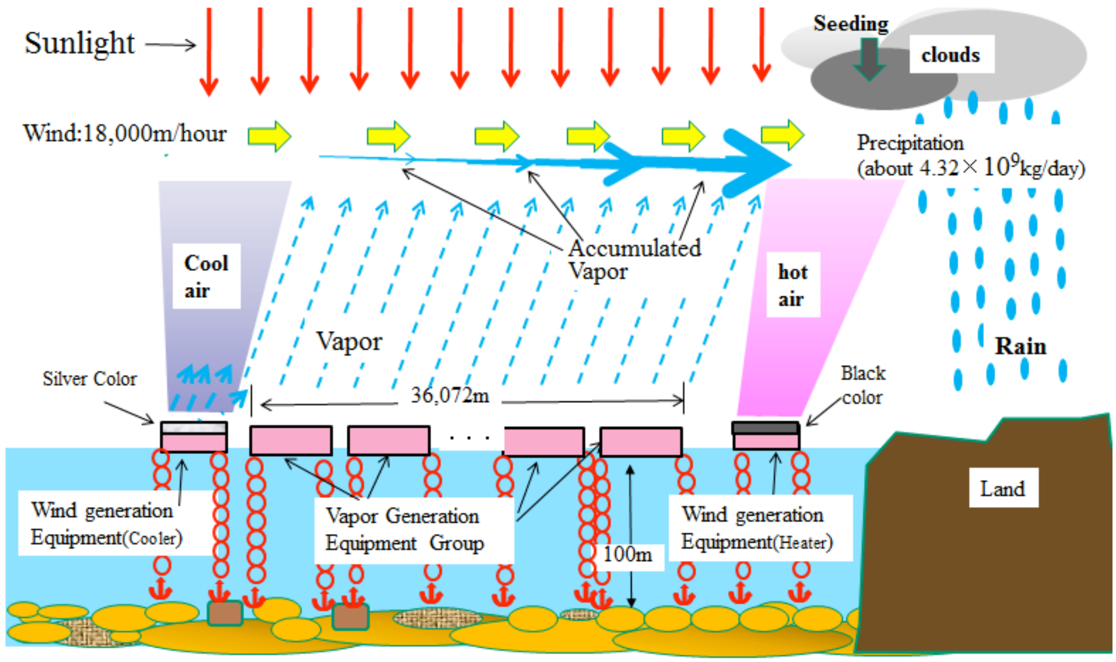

Figure 3: The proposed artificial rain system, vapor and rain.

18,000 meter/hour and the wind direction is from the sea to the land, it takes two hours for the wind to completely pass above the VGE group (approximately 36,000 meters in length). The VGE group transforms 0.67 kg of water to vapor per one meter square in one hour. Therefore, the amount of vapor, which is accumulated at the end of the VGE group near land, is about 1.34 kg (=0.67 × 2) in one meter square per hour.

2.2. Wind Generation Equipment

In many regions, wind blows from the sea to land in the daytime. This is called sea breeze. This sea breeze effect plays an important role in transporting vapor created by the VGE group to land. The direction, height, and speed of the sea breeze depend on the specific region. The prevailing westerly or trade wind blows constantly, and for the most part, at a constant speed and direction. However, these winds are changeable according to seasons.

Vapor is transported to land by this wind. The setting of the VGE group is adjusted to the specific characteristics of this wind on a case-by-case basis. If the direction and speed of the wind can be controlled, the VGE group would be able to provide a specific amount of artificial rain at a specified time and to a predetermined area.

The proposed Wind Generation Equipment (WGE) would be used to create a modified wind pattern to support the delivery of artificial rain as part of this proposed new system. It supports the generation of wind which would be used to carry vapor generated by the VGE to land. The key design features of the WGE are that it is composed of only a floating body and that the surface of the body is a specific color, depending on whether the floating body is to heat or cool the air. The surface of the floating body of the WGE used as a heater is colored black. This allows for solar energy to be changed into heat energy, which heats the surrounding air, including the vapor generated by the VGE. If the solar energy is 1.0 kilowatt per 1 meter square per hour, then heat energy of the WGE could be equal to 1.0 kilowatt per 1 meter square per hour. The surface of the floating body of the WGE used as a cooler is colored silver or white. Therefore all of the sunlight energy could be reflected to the sky, and the surface of the floating body and surrounding air above it are cooled lower than the air immediately above the sea surface. The total heater or cooler energy to be created by WGE depends on the total area of WGE. The total size of the WGE's heater determines how high the vapor is able to rise, and how far from the sea the artificial rain will be able to be. The location of the WGE (heater and cooler) determines the direction of wind flows, and it is designed by taking account of sea breeze, the prevailing westerly and trade wind.

The total amount of energy required to heat (or cool) the surrounding air is very large and increases (or decreases) depending on the air temperature. For example, a heater that is 1 km square in area emits about 1.0 million kilowatt-hour heat energy per hour. High temperature air is lighter than surrounding air, and the speed of vapor rising upward is high. Wind blows from an area with a cool temperature to that with a higher temperature. Therefore, taking into account the sea breeze effect, the prevailing westerly and trade wind, the selection of location and size for a WGE can be assisted by means of weather simulation, and the direction and the speed of wind can also be planned and controlled.

3. DESIGN AND FUNCTION

Example A is described under the hypothesis below. In Example A, the VGE group as shown in Figure **2** is applied to a region as shown in Figure **3**.

(1) Hypothesis 1: In this region, there is a sea breeze with a speed equal to 18km per hour, and the WGE supports the generation and control of wind. The WGE is set at the head and tail of the VGE group as shown in Figures **3** and **4**. Vapor generated by the VGE group is heated by the WGE, and transported by a sea breeze and/or wind which go from the sea to land according to setting direction of the WGE.

(2) Hypothesis 2: The region where artificial rain is required is arid with low levels of precipitation. It has 300 days of sun per year. Therefore, the artificial rain system makes vapor and clouds that will provide artificial rain to agricultural areas on sunny days. The VGE has more than 1000 Watt-hour solar energy per square meter per hour, and can generate 1.0 kg of vapor per hour per meter square. Between 10:00 to 16:00 o'clock, the VGE can transform 1.0 kg of sea water to vapor per hour per meter square. This means the VGE group transforms 0.67 kg sea water to vapor per hour per meter square. It can amount to 4.0kg of vapor per meter square during one day.

(3) Hypothesis 3: At 18:00 o'clock, it becomes cool and rains in the area where vapor or clouds have formed. Seeding is done, if necessary.

(4) Hypothesis 4: Under nature condition of the sea surface, nature vapor generates on the sea surface. An amount of nature vapor depends on a region, and nature vapor does not decrease artificial rain precipitation. Therefore nature vapor is neglected in following calculation, and equation for precipitation shows the minimum value.

In Example A, the total amount of artificial rain precipitation (Pt) is shown by Eq. (1).

$$Pt = Vo \times Vw \times Vlen \times Vd \times 6 \qquad \text{Eq. (1)}$$

Vo: The amount of vapor to which the VGE changes water per hour per meter square (kg/(hour×m^2)).

Vw: The width of the VGE group (meter),

Vlen: The length of the VGE group (meter),

Vd: Density of the VGE group. (÷ the width of VGE / (the width of VGE + the interval between VGEs)). In the case shown in Figure **3**, Vd is about 0.67,

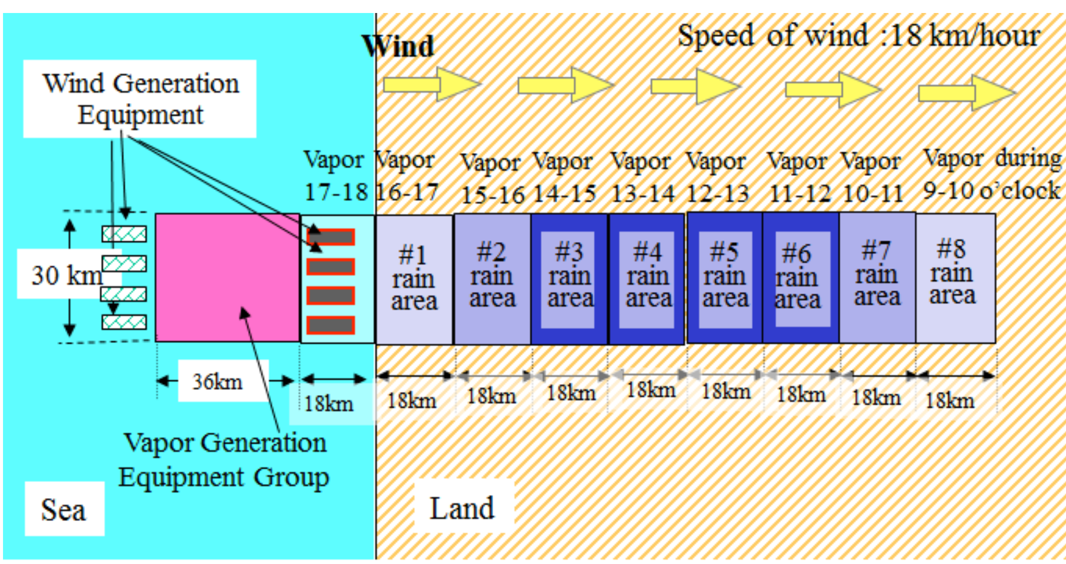

Figure 4: Artificial rain areas.

Wsp: Speed of wind (meter/hour).

The maximum density of artificial rain precipitation (Pm) is shown by Eq. (2).

$$Pm = Vo \times Vd \times (Vlen \div Wsp), \text{ if } (Vlen \div Wsp) \leq 6$$
$$= Vo \times Vd \times 6, \text{ if } (Vlen \div Wsp) > 6 \quad \text{Eq.} \quad (2)$$

Artificial rain areas in this region are considered as shown in Figure **4**. Pt is equal to about 4.32×10^9 kg, and Pm is equal to 1.34 kg per meter square, in a case that Vo=1.0 kg/hour/m^2, Vw=30,000 m, Vlen=36,000 m, Vd=0.67, Wsp=18,000 m/hour. If it is assumed that when it is 18:00 o'clock, all of the vapor or clouds changes to rain, and #3 to #6 areas as shown in Figure **4** have 1.34 kg per meter square precipitation, and areas such as area #2 and #7 have 0.67 to 1.34 kg per meter square precipitation. However, in a real case, rain does not occur over a very short time, such as one second. Therefore, the amount of precipitation in areas #3 to #6 is not equal to 1.34 kg per meter square, but is nearly equal to1.34 kg per one meter square. An accurate amount of precipitation is reported by rain gauges. When precipitation in an area is small, the area can have more rain by means of the artificial rain system during another day.

Pm is different from each case. In the case where wind speed is very high (e.g., Wsp=36,000m/hour), and the length of the VGE group for a region is short (e.g., Vlen=7,200m), then cloud density will be low (e.g., 0.13 kg per one meter square), meaning that precipitation in the region might not be realized even if seeding is done. In this case, the length of the VGE group would need to be longer in order to produce the conditions required for artificial rain. On the other hand, in the case where wind speed is low (e.g., Wsp=3,600m/hour), and a length of the VGE group for the region is short (e.g., Vlen=7,200m), Pm is equal to about 1.3 kg of precipitation per meter square in the region.

In Example A, the amount of rain in each rain area can be clearly calculated by Eq.(2) as shown in Figure **4**. However, the amount of actual rainfall for a given rain area may be different from the amount planned for the same rain area, as shown in Figure **4**. The actual amount of precipitation in a rain area may be different from the value planned using the precipitation operation function. However, an accurate value for the actual amount of precipitation in the rain areas can be provided through the use of rain gauges. Therefore, the amount of actual precipitation in an agricultural area can be calculated and adjusted to the object value (e.g., 300 kg per meter square per year) by the means of controlling the times and areas of artificial rain. When artificial rain in an area is required, vapor or clouds generated by the VGE group are transported to the area by wind, and the existing cloud seeding is applied in the area, if necessary. As a result the area has an appropriate amount of artificial rain.

Plants absorb water from their roots and transpire vapor from their leaves. The amount of water or vapor is different between kinds of plants, and depends on various factors such as temperature, humidity and sunlight levels. For example, a cactus requires about 0.025 kg water per day, while a birch requires about 40 to 300 kg water per day. A palm, which stands alone, requires about 500 kg water per day. A palm, which stands in a tropical forest, requires about 2 to 3 kg water per day [9].

This paper considers Case A. Case A is that an object value of precipitation for a plant is equal to 400 kg per one year per square meter, and the plant transpires 300kg of vapor from their leaves when it has 400 kg of precipitation. In Case A, it is not so important for the plant that the actual precipitation is 390 kg or 410kg precipitation per one year per square meter, because even if 390 kg precipitation per one year per square meter may be not enough for its growth, the plant will be able to survive. Before artificial rain is produced, consideration must be given to the potential effects on any areas adjacent to area planned to receive artificial rain. Using the precipitation function to estimate the potential effects, the artificial rain will be produced only when the potential effect on these other lands is small or negligible.

In Case A, how much of a given agricultural (or "plant") area has received enough precipitation is calculated very roughly as follows, as shown in Figure **5**.

i) The VGE group makes about 4.0 kg of vapor per one day (6 hours) and per square meter. The VGE group with 1,080 km square, therefore, makes 4.0 kg vapor per square meter per day during 300 days, as described in Example A. In other words, the VGE group with area of 1,080 km square can make 1,200 kg of vapor per square meter per one year by the proposed artificial rain system.

ii) As Figure **5** shows, #1 Plant Area is 1,080 km square and is near the location of the VGE

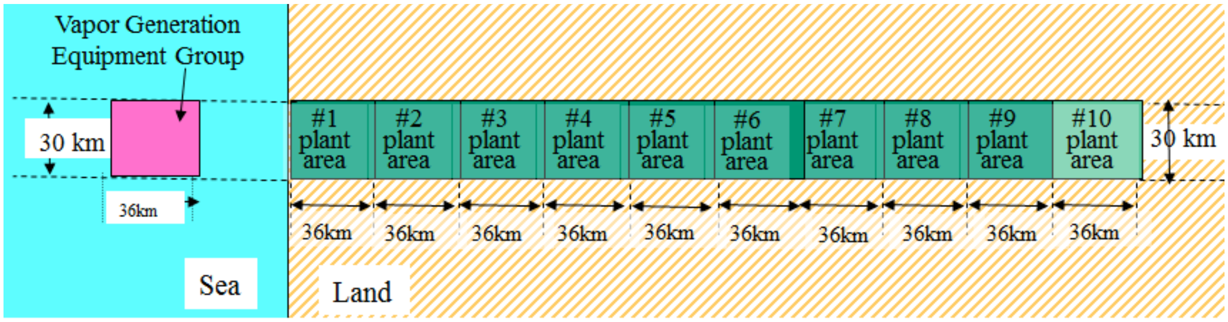

Figure 5: Plant areas where the proposed artificial rain system produces rain.

group. This agricultural area receives 400 kg of precipitation per square meter per year *via* the artificial rain system. Plants within this area transpire 300 kg of vapor per year per meter square. The agricultural areas other than #1 Plant Area can receive 1,100 (=1,200 – 400 +300) kg of precipitation per square meter per year in an area 1,080 km square. The #2 Plant area is 1,080 km square and also can receive 400 kg of precipitation per square meter per year Plants in this area also transpire 300 kg of vapor per square meter per year. This pattern continues through to #9 Plant Area, which is 1,080 km square and can receive 400 kg of precipitation per square meter per year. As a result, the Plant Areas #1 through #9 are each 1,080 km square and can receive 400 kg precipitation per square meter per year. This results in a total area for agricultural production of 9,720 km square.

iii) The precipitation is operated and realized by a precipitation operation function which has a real time precipitation report connected to rain gauges. Case A shows an ideal calculation of an artificial rain application. A real application of artificial rain might produce more than 400 kg of precipitation per square meter per year. In general, plants that receive at least about 400 kg of precipitation per square meter per year are able to sustain normal growth.

4. THE COST OF 1 KG OF ARTIFICIAL RAIN

The cost of producing artificial rain is mainly made up of equipment costs for the proposed artificial rain system, maintenance costs of the proposed artificial rain system (about 10% of the equipment cost), and energy costs for generating vapor. Most the total equipment cost is for the VGE group, with the remaining equipment costing roughly 10% of the costs for the VGE group. The energy cost for making vapor is free, because the proposed artificial rain system uses only solar energy to make vapor.

The VGE consists of floating material F (e.g., floatation tubes), and sheet S, which is likely to be cotton cloth. The cost of 1 kg artificial rain (C1) is shown by Eq.(3), and is about 0.002USD.

C1 ≅ (equipment cost + maintenance cost of artificial rain system + energy cost of artificial rain system) / (total amount of artificial rain during VGE life time) Eq. (3)

≅ (equipment cost × 1.1) / (total amount of artificial rain during VGE life time) ≅ (VGE cost × 1.1 × 1.1) / (total amount of artificial rain during VGE life time) ≅ (cost of one meter squire of VGE × 1.1 × 1.1) /(Total amount of Vapor generated by VGE with 1 meter squire area during VGE life time) ≅ 1.5 USD × 1.1 × 1.1/(6 × 0.67 × 300 × 1) ≅ 0.002 USD Eq. (4)

Note: It is supposed that the life time of the VGE is equal to one year.

5. CONSIDERATIONS

(1) The proposed artificial rain system does not require any land-based buildings, equipment or energy sources. On the other hand, it requires a large sea or lake surface area for setting up the VGE group. It is also necessary that in the region requiring artificial rain, the air temperature is more than 25 degree centigrade and that solar power is more than 800 watt per meter square per hour. The proposed artificial rain system does not use oil or electric energy and does not produce CO_2, because it uses only sunlight energy in order to make vapor.

(2) In an area where much vapor has been generated by the VGE group, and where cloud

seeding is applied, there is a high possibility that artificial rain can be produced. The likelihood of producing artificial rain depends on temperature, humidity and wind characteristics of the region requiring artificial rain. Therefore, when the proposed artificial rain system is applied to a region, it is necessary to develop a sophisticated precipitation operation method suitable for the region in order to control the desired amount, timing and area for the application of artificial rain.

(3) The proposed artificial rain system can serve at any one time a region with a total area of about 9 times the VGE group area, as shown in Case A. The total area depends on the length of the VGE group and how much precipitation is required by specific plants per meter square. If the target value of precipitation is 800 kg per square meter per year and an amount of transpiration is 700kg per square meter per year, the total plant area is about 5 times the VGE group area.

(4) The proposed artificial rain system has some disadvantages. One is that it may cool the water and air in the area where the VGE group is located. As the VGE group would create an area of shadow under it, there is a small possibility that it would cool the water in this shaded area significantly. However, the bodies of water envisioned for use with this system would be very large and in continuous movement. An interval between the VGE as shown in Figure **1** is equal to 1 meter, allowing about 33% of sunlight to pass into the water and provide solar energy to the water, plants and animals. Therefore, the VGE group may not have a significant effect on the aquatic environment, and in particular, when the location of the VGE group is on the stream of a sea current, where there may be no effect. The other disadvantage is that it may produce rain in an area where rain is not required. Where the proposed artificial rain system is to be applied to any region, these disadvantages should be paid attention to.

6. CONCLUSION

(1) It has been shown that the proposed artificial rain system using the VGE group and WGE could be used to create artificial rain, as well as controlling the amount, area and timing of the artificial rain to be applied. It can provide a large amount of precipitation without CO_2 emissions or the consumption of oil or electric power. This system would not have significant effects on the immediate aquatic environment.

(2) The proposed artificial rain system could be implemented at a low cost, or about 0.002 USD for 1 kg rain.

(3) This paper presents preliminary investigations into the principles and practical potential of the artificial rain system as described. However, it would be necessary for a large scale VGE group and WGE to be developed and tested in order to study the actual operation and maintenance of this new technology in detail.

(4) The American Meteorological Society discusses inadvertent weather modification and makes associated recommendations [10]. How to use the proposed artificial rain system should be studied and considered from both viewpoints of global warming and planned weather modification on a local and regional scale.

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