Cherish renewable aerial water vapor as it is a huge hidden energy resource

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Abstract

This paper emphasizes how great energy hidden in ubiquitous aerial water vapor and how spectacular and subtle in natural evaporation by visualizing tedious thermodynamic data in vivid macroscopic and microscopic scale with different gauges such as kj/kg, eV/molecule, photonic wavelength per single step of water molecular clusterization during condensation for energy density estimation, mm/day, nm/s for evaporation rate average calculation. Condensation is first time described as special invisible infrared combustion, and it is proved that it is theoretically possible to convert its latent heat to high grade thermal energy.

§1. Introduction

Energy and freshwater crisis push humankind rethinking whether it is possible to utilize the background heat from our living environment.

Everyone witnesses the Sun cooking our Earth by here half side or there half side with the 24 hours rotation rhythm.

Most of the solar energy is absorbed by surface water then tremendous natural water vapor is generated and rising to atmosphere.

On the other hand, as a part of complete constant water circulation, somewhere lightening and storming events take the water vapor down to Earth surface gain, and the released vapor latent heat is mostly dumped to deep space and the leftovers return to Earth via infrared light dissipation.

Can our human beings only be audience of such a water circulation, or can we be the actor to partially dominate it on demand?

In fact, we can partially dominate the water circulation, as evidenced by the rare

occasional projects of artificial precipitation, but no benefit of energy harvest.

At first glance, it seems impossible to harvest energy from background heat on basis of thermodynamic 2nd law, but deeper research will reveal a backdoor to circumvent.

Anyway, it is worthwhile to further investigate vapor related thermodynamic properties by whatever means.

§2. Is latent heat of cold vapor not as powerful as hot vapor?

The answer is NO! In fact, cold vapor is more powerful than hot vapor.

By intuition, you may probably give the answer to hot vapor, but the right answer should be the cold vapor if careful calculation done.

From any thermophysics handbook, you can get these data: for the 0°C water vapor, **latent energy** = 2374 kj/kg; for 25°C, reduced to 2304 kj/kg.

You can also get: for 101°C vapor or say steam, condensation will release latent energy = 2507.2-423.3 = 2084kj/kg. Obviously it is less than 2374 kj/kg in 0°C.

The relevant experimentalists even suggest an empirical formula in cubic function:

$L_{water}(\textbf{T})$ = (2500.8 – 3.36$\textbf{T}$ + 0.0016$\textbf{T}^2$ – 0.00006$\textbf{T}^3$) kj/kg,

where the temperature **T** is taken to be the numerical value in °C.

The differential function:

$$\frac{dL}{d\textbf{T}} = -3.36 + 0.0032\textbf{T} - 0.00018\textbf{T}^2$$

Obviously, in regular temperature range, $\frac{dL}{dT} < 0$, and that means the higher the temperature, the lower the latent heat. So don't despise cold vapor anymore!

Above calculations clearly demonstrate the powerful energy hidden in our daily ubiquitous breath air.

§3. Evaporation rate with microscopic description and energy equivalence

In average year, for a typical district of **1000 mm precipitation per year**, every square meter land will roughly evaporate water 1000/365 mm = **2.74 mm/day** in average.

By changing the time scale to second, the 2.74 mm/day is equivalent to 2.74/(24*60*60) = 3.2*10^{-5} mm/s = **32 nm/s**, i.e. 32 nanometers per second in thickness reduction.

The diameter of water molecule is about **0.4nm**, or **4Å** (angstrom). So, year-averagely speaking, 32/0.4= 80 layers of water molecular "skin" on surface will be vaporized in just 1 second.

Theoretically the water evaporation rate is proportional to **saturated pressure - real vapor pressure** and temperature. In real word, lots of factors in effect, even include wind velocity, so it is complicated very much to deduce an official formula. However there exist a few of empirical formulas.

For example, the EngineeringToolbox website proposes an empirical equation:

Gs = (25 + 19v)A(Xs – X)/3600

The **v** is the wind speed.

A is the water surface area.

Xs is the theoretical ratio of mass of water in saturated air; **X** is the real respective value.

Example - evaporated water from a swimming pool:

For a swimming pool with water temperature 25°C, the saturation humidity ratio is 0.02 kg/kg. With an air temperature of 25°C and 50% relative humidity - the humidity ratio in air is 0.0098 kg/kg .

For a 25m x 20m swimming pool and 0.5m/s velocity of air above the surface, the evaporation amount can be calculated as:

G_s = (25 + 19 (0.5 m/s)) ((25 m) (20 m)) ((0.02 kg/kg) - (0.0098 kg/kg)) / 3600

= 0.049 kg/s.

The evaporation rate in thickness change is about $0.049/((25*20)*1000) = 10^{-7}$ m/s = 100 nm/s = 0.1 μm/s. Of course, such a tiny transience is not observable, because even the surface ripple is exponentially greater by some orders of magnitude.

If the air is totally dry, i.e. the relative humidity 0%, the calculated 100nm/s will be further doubled.

§4. Areal power density of ambient air

The areal power density is directly relevant to evaporation rate, so as to climate zone.

For a typical middle latitude zone, average precipitation is about 1 meter or 1000 mm per year, it is equivalent to $1/365 * 1000 = 2.7$ kg/m^2/day.

As vaporizing 1kg water need about 2.3MJ solar energy, so the ground areal energy density of absorption per day = 2.7*2.3= 6.2 MJ/m^2/day.

In consideration of water circulation equilibrium, the potential latent energy emission during precipitation equals to the absorption.

Thus for atmospheric heat reclaiming apparatus, if not counting the horizontal air moisture mass transfer, its max horizontal areal power density = $6.2*10^6 /(24*60*60) =$ **72 watts/m^2**.

Or 0.072*24 = **1.7 kwh/m^2/day** for daily energy density. Of course, all those energy should be credited to the contribution of the Sun cooking the Earth.

It is said that the Sun casts light energy at the rate of circa 1000 w/m^2 on our Earth, the above calculation shows that 72 w/m^2 is used for evaporation. In other words, the Sun uses about 7.2% of its gross solar energy for vapor production. So it is never a small deal in the latent energy of vapor!

The calculated result is just the yearly average value. In summer, it is easily rising double. In city, those values can be significantly less than in rural area, as in rural area the vast crops or grass land will **evapotranspire** more water vapor because of vegetation mother nature.

For water body, e.g. river, lake, ocean where are the major sources of water vapor, the local areal power density is most likely the highest, probably most solar energy therein is used for evaporation except some percentage reflection.

§5. Thermal power capacity rating by condensation rate

The **condensation rate** is the base for the system capacity rating.

Given the water vapor minimal releasable latent heat is about **2.1 MJ/kg**, for every 1kw thermal output capacity, i.e. 1000 Jules per second, condensation rate should be 1000/(2.1*10^6) = 0.0005 kg/s = **0.5 g/s**, that means at least 0.5 grams vapor should be condensed to liquid water per second to reach power 1 kilowatt.

For heat engine, the mechanic work capacity is more concerned, but generally speaking, it is about 10% to 30% discount of the total thermal capacity. That means most of energy still exists in thermal state after partial thermal energy was converted to mechanic energy. Even so, do not feel regret if the carrier medium can be regenerated for next cycle unless it is dumped out of system.

So, the mechanic work capacity rate can be estimated in vapor condensation rate from (0.5 g/s/kw)/10% = 5 g/s/kw to (0.5 g/s/kw)/30% = 1.7 g/s/kw, averagely circa (5+1.7)/2= 3.4 g/s/kw.

§6. How much water in ambient air?

The moisture amount of real air is highly depends on the ambient temperature, because the saturated amount is the function of temperature. The higher the temperature, the more water the air can contain.

For example, in frozen point 0℃, max **5 g/m^3** (grams per cubic meter); 25℃, max **23 g/m^3**; 30℃, max **30 g/m^3**; 40℃, max **51 g/m^3**; -20℃, max **0.9 g/m^3**.

§7. Volume energy density of ambient air

Don't under-estimate the great energy hidden in the moisture, even simple calculation will amaze you.

For example, at frozen point 0℃, 1 atm:

water vapor internal energy **2374** kj/kg, liquid **0** kj/kg, the phase change from gaseous to liquid will result in internal energy loss 2374 - 0= **2374** kj/kg.

For the saturated water 5 g/m^3, the **potential energy density** = 0.005 * 2374= **11.87** kj/m^3, if we can find a way to condense the cool vapor.

The specific heat capacity of dry air is about 1 kj/kg/K, and air density is 1.29 kg/m^3.

So if all the 5 g vapor condensed, the released energy 11.87 kj can raise the temperature of the same volume 1 m^3 air up to ΔT = 11.87/1.29 = 9.2℃.

At room temperature 25℃, 1 atm:

water vapor internal energy 2409 kj/kg, liquid 105 kj/kg, the phase change from gaseous to liquid will result in internal energy loss 2409 – 105 = 2304 kj/kg.

For the saturated water 23 g/m^3, the contained energy density = 0.023 * 2304= 53 kj/m^3.

So if all the 23 g vapor condensed, the released energy 53 kj can raise the temperature of the same volume 1 m^3 air up to increment of ΔT = 53/1.29 = 41.1℃, then the imagined autonomously heated air temperature = 25 + 41= 66 ℃, what a big temperature increase in situ!

§8. Equivalent liquid temperature of water vapor

At temperature 100 ℃, 1 atm, water vapor internal energy 2506 kj/kg, liquid 419.1 kj/kg, The phase change from gaseous to liquid will result in internal energy loss 2506 - 419.1 = 2086.9 kj/kg.

The specific heat capacity of liquid water is about 4.2 kj/kg/K which is just 1/500 of the phase change latent heat. That means the latent heat in 1 kg vapor is roughly equivalent to the heat that will be consumed to heat 5 kg water from 0℃ to 100℃, or virtually from 0℃ to 500℃ for same 1 kg water if there would be no phase change in any temperature range.

In a sense, even the vapor of water in frozen point 0℃, it can still be regarded as circa 500 ℃ **equivalent liquid temperature**, even more hotly than boiling point vapor, because cold vapor has more latent energy than hot vapor.

§9. Molecular level energy equivalence in microscopic condensation

Let's zoom-in to microscopic world to see the equivalence.

1 kg H_2O = 1000/18 = 55.56 moles, every mole contains $6.022*10^{23}$ molecules, i.e. the Avogadro constant, then every single molecule should be credited with internal energy change $2086.9*10^3/(55.56*6.022*10^{23})$ Jules = $6.24*10^{-20}$ J.

Because 1 eV (electron volt) = $1.6*10^{-19}$ J, so every H_2O molecule will release energy when condensed to liquid: $6.24*10^{-20}/(1.6*10^{-19})$ = 0.39 eV.

In contrast, the 1℃ or 1 K temperature change without phase change is about 0.39/500 = 0.00078 eV per molecule.

Therefore, water vapor condensation is exothermal at averagely **0.39 eV per molecule**.

By 6 times 0.39 eV, we can write down the condensational quasi-chemical reaction equation to "synthesize" most common 6 molecules cluster natural liquid water:

$H_2O + H_2O + H_2O + H_2O + H_2O + H_2O \rightarrow 6H_2O$ + 2.34 eV
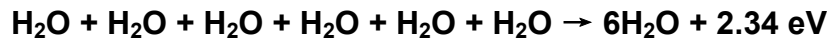
Above equation is only true in sense of mathematic energy equivalence, though multi-stage reaction is more likely true in real microscopic world.

§10. Photon equivalence in microscopic condensation

Given **E** = 0.39 eV, plank constant **h** = $6.63*10^{-34}$ js = $4.14*10^{-15}$ ev·s, light speed c = $3*10^8$ m/s, according to photon energy formula: $E = h\nu$, we can get photon wavelength:

$\lambda = \frac{c}{\nu}$ = **$3*10^8/9.4*10^{13}$ = $3.19*10^{-6}$ m = 3.19 μm**

In other word, averagely speaking, calculation shows that every single H_2O molecule may emit a photon of infrared of wave length 3.19 μm while it joins with the growing cluster. Until now, it is just a guess based on the calculation and energy conservation.

Compared with the well-known 13.6 eV photon emission during hydrogen atomic orbital jump, this phase change energy 0.39 eV is never a big deal, but a significant deal in massive water vapor condensation.

§11. The epic experiment of condensation-to-IR and its explanation

In 1968, two scientists Potter W R, Hoffman J G, pioneeringly found that vapor condensation can radiate infrared (IR). The paper [1] of findings was published in the volume 8 of Infrared Physics Journal of that year. Until now lots of experiments by different scientists in different laboratories have verified the same fact of IR emission induced by phase change.

The **fig. 1** is cited from the said precursor's experiment report. It shows the radiation

spectrum of boiling point vapor condensation. At the range of 1 to 4 micrometer (μm), the integral intensity is 4 times bigger in average than the Planck's radiation in same temperature. 2 main emission bands are seen at 2.1 μm and 1.54 μm wavelengths. The intensity of both bands exceeded the background radiation by a factor of 10. Probably 3rd (2.5 μm), 4th (3.2 μm) and 5th (4 μm) that were not mentioned by the authors can be recognized on the curve.
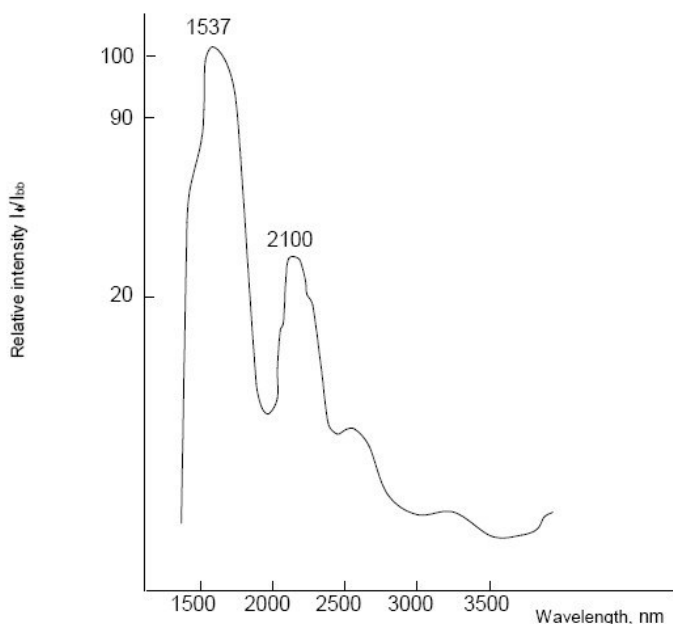
Fig. 1: water condensation infrared spectrum (by courtesy of publication of Potter el la)

The serendipitous finding in the experiments is that the 4th peak 3.2 μm is coincidently almost the same value with the aforementioned average equivalent photonic wavelength 3.19 μm!

Let's again and again review the 5 peak wavelengths in the experimental data: 1.54 μm, 2.1 μm, 2.5 μm, 3.2 μm, 4 μm.

The observed 5 radiation peaks (1.54 μm, 2.1 μm, 2.5 μm, 3.2 μm, 4 μm) seem possible to be explained within following paragraphs as:

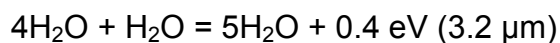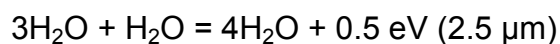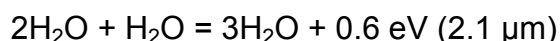The shorter the wave length, means the stronger the energy of photon. If the average energy in 3.2 μm is regarded as standard energy 100%, then the 5 peaks can be arrayed in energy sequence: 200%(1.54 μm), 150%(2.1 μm), 125%(2.5 μm), 100%(3.2 μm), 75%(4 μm).

Assuming 6 molecules of H_2O can build a stable cluster, so 600% standard energy will be emitted after cluster shaped. Because the individual cluster shaping dynamically with H_2O molecule joining one by one in different difficulty level, not every single molecule

does contribute same standard energy 100%, or say the energy distribution is not equal among the 6 molecules.

Just imaging the whole clustering procedure: the 1st H_2O molecule seeking the 2nd molecule is relatively a hard job, so it may consume double energy (200%), that may be why we see the 1st peak 1.54 μm. The 3rd molecule joined with 150% energy, that may be why we see the 2nd peak 2.1 μm; the 4th joined with 125%, that may be why we see the 3rd peak 2.5 μm; the 5th joined with 100%, that may be why we see the 4th peak 3.2 μm; the 6th last one closes the cluster with 75%, that may be why we see the 5th peak 4 μm. Totally 650% standard energy is involved. The extra 50% of standard energy may be used for overhead of inter-cluster bonding.

If 6 molecules of H_2O is the stable liquid molecular after condensation, then the quasi-chemical chain reaction equation may be conjectured roughly as follows:

$H_2O + H_2O = 2H_2O + 0.8$ eV (1.54 μm photon)

$2H_2O + H_2O = 3H_2O + 0.6$ eV (2.1 μm)

$3H_2O + H_2O = 4H_2O + 0.5$ eV (2.5 μm)

$4H_2O + H_2O = 5H_2O + 0.4$ eV (3.2 μm)

$5H_2O + H_2O = 6H_2O + 0.3$ eV (4 μm)
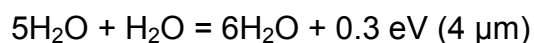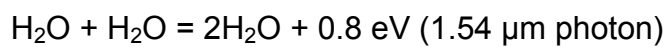
According to the **Wien's law**, every above 5 peak wavelength should correspond to a virtual blackbody radiating temperature that can be calculated by **$Tb = 2890/\lambda$**.

For the 1st condensation peak 1.54 μm, $T_1 = 2890/1.54 = 1877$K$= 1877-273 = 1604$℃；

For the 2nd condensation peak 2.1 μm, $T_2 = 2890/2.1 = 1376$K$= 1376-273 = 1103$℃；

For the 3rd condensation peak 2.5 μm, $T_3 = 2890/2.5 = 1156$K$= 1156-273 = 883$℃；

For the 4th condensation peak 3.2 μm, $T_4 = 2890/3.2 = 903$K$= 903-273 = 630$℃；

For the 5th condensation peak 4 μm, $T_5 = 2890/4 = 722$K$= 1877-273 = 450$℃；

The above result may astonish you: all the condensation IR photon is so extreme hot even it can almost challenge burning fire or combustion!

Therefore, we find a backdoor: it is possible to invent a smart heater for using aerial water vapor as "fuel" to achieve far hotter temperature than vapor itself sensible temperature and such still complies with thermodynamics 2nd law, because the condensation induced photons are high temperature, though the statistic gauge temperature of vapor is low.

Although intuitively optical method can be used to exploit the said backdoor, however other means are still possible to absorb the induced infrared photons, e.g. properly designed ejector [2].

§12. A brand new theory – Invisible IR Combustion

Supported by the aforementioned quasi-chemical reaction equations, and its equivalent liquid temperature, I boldly present a brand new theory – Invisible IR Combustion. Also I predict:

Just like visible regular combustion, there must be **invisible IR flame** perhaps in shape of plume during condensation process, and the IR flame is just consisted of the rising heated air elements that are pushed around mechanically during the water inter-molecular clustering process.

So in a sense, the condensation process is an invisible quasi-combustion process with no substantial difference with the regular gasoline combustion except in visibility and the quantity of the energy emission and no consumption of oxygen.

§13. Quiz: 1 kg aerial water vapor = how many kg gasoline?

Heating value is an important index of fuel.

In a sense, aerial water vapor is a special 'fuel', its releasable latent energy can be regarded as its heating value about 2.3 MJ/kg.

Compared with the gasoline's heating value 47 MJ/kg, the 2.3 MJ/kg of water vapor is about 5% of gasoline, but still remarkable and no need to pay, it is totally free!

Therefore the equation is:

1 kg aerial water vapor = 0.05 kg gasoline

Not like the combustion, the condensation is not reviewed as chemical reaction, but in a sense, it is a quasi-chemical reaction and quasi-combustion, because vapor molecule generally exists in single, but liquid molecule exists in cluster of multiple basic molecules by hydrogen bonding, for example, the typical **$6H_2O$** polymerized clathrate stable molecule.

Thus, why not cherish the omnipresent environment water vapor?

§14. Ejector-based implementation

Generally speaking, there are 3 ports with an ejector, 2 ports are for input flow, and 1 port is for output. Thereof the 2 input ports, 1 is used for liquid input, the other is for gas or vapor input.

The ideal structure of ejector can make supersonic shockwave happen when input vapor flow entangled with input motive liquid flow. The shockwave energy is from the release of vapor latent heat during condensation. The shock can result in higher output

pressure than input pressure of liquid flow, i.e. **pressure augmentation**. See reference 5~12 for existed applications or theory analysis.

The induced pressure differentiation can at least enable close-loop vapor-liquid mix compellent condensation autonomous, further be optionally used to drive turbine for electric generation, or simply shorted for waste heat re-utilization. Following figure sketches such a system.
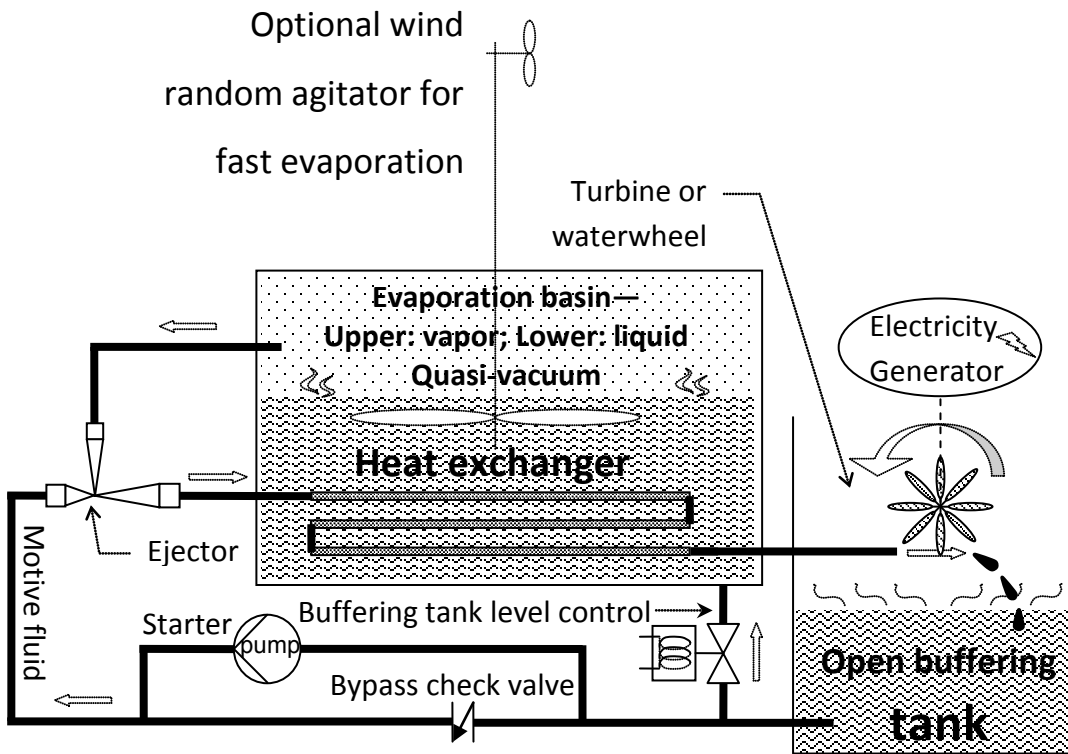
Fig. 2: ejector-based heat engine that recycles latent heat of aerial water vapor

The optional stirrer can make use of random wind power so as to quicken the evaporation rate.

To maximally use solar sunshine and save ground lot area, the shallow water trays can be stacked in multiple layers vertically, but sunshine should be reflected to every transparent trays by side mirrors array, otherwise only the top tray can catch almost full solar energy.

Fig. 3 illustrates such an important improvement for the evaporation basin module in **fig. 2** ambient air moisture latent heat engine system.

As per aforementioned calculation, for every layer, its average power density is about 72 w/m^2, thus the stacked module will linearly increase its gross power density by the layer quantity **N** times, i.e. **N*72** w/m^2.

There is so-called Asakawa Effect that can greatly quicken evaporation rate by applying electrostatic strong field cross liquid-vapor interface, i.e. the electrohydrodynamic method. Usually the amplification is up to 10 times faster than natural evaporation.
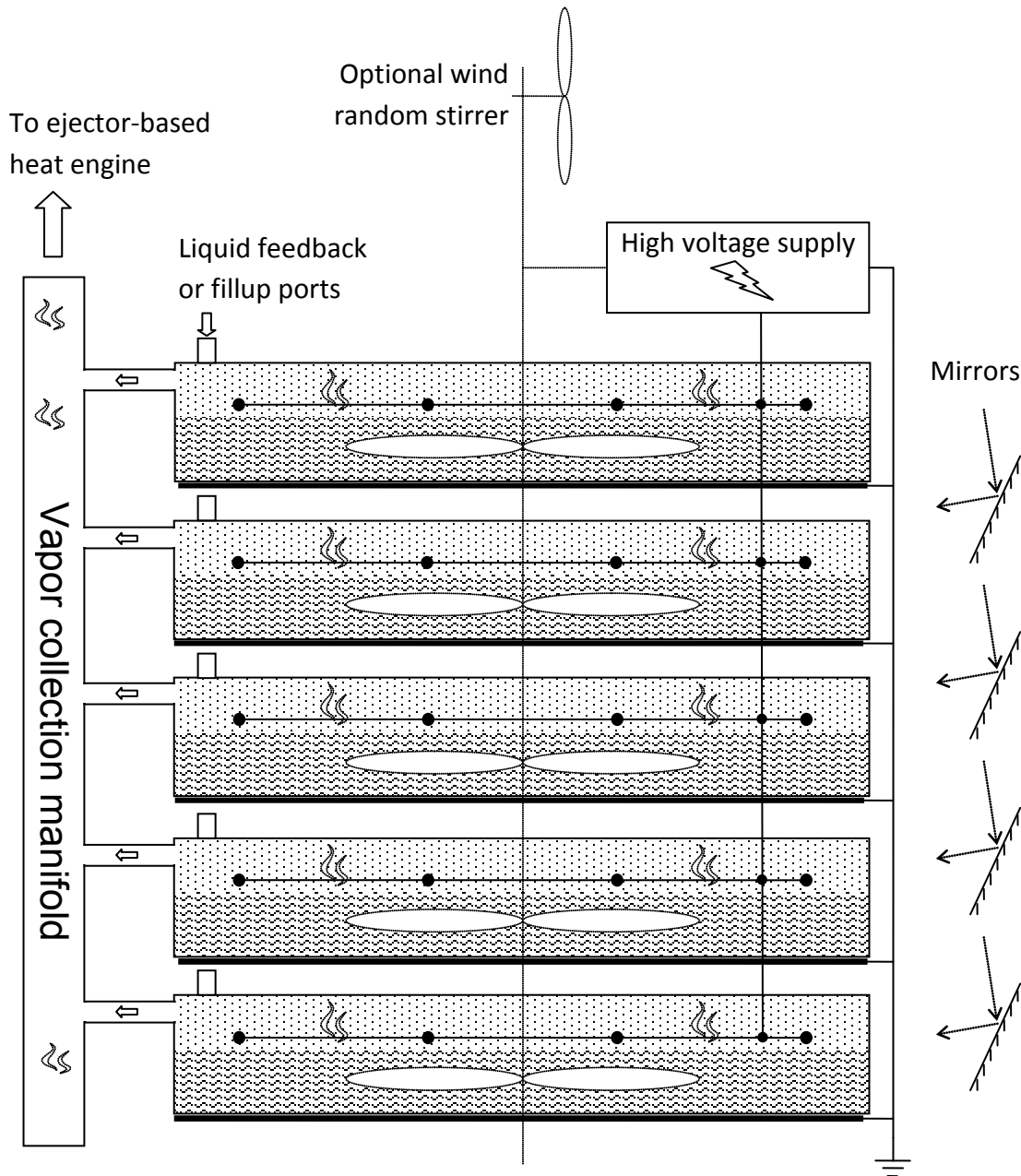
Fig. 3: improved evaporation module with multiple stacked shallow trays

The energy consumption for providing the said effect is insignificant, so it is just the neglectable overhead management consumption.

§15. Outlook to the profound influence

Atmosphere contains huge vapor latent energy. Converting it to usable heat or power in economic way is a hard challenge because of its nature of low grade heat.

Only by condensation, can the latent heat hidden in vapor be released out. The usable energy always means output of large joules in a short unit time. The higher power we need, the quicker condensation must be. Generally speaking, condensation often impresses us a slow procedure, hence flash condensation may be just a dream, though we can realize flash evaporation in many applications.

For engineering application, controlled condensation rate is just what we want, because it determines the output capacity rating. However, even the seemingly small 0.5g/s/kw is not an easy controllable parameter.

Furthermore, the regular traditional condensation is done by cooling source, such that means a deep lower temperature reservoir (heat sink) than atmosphere is needed. But maintaining a cooling source is another costly challenge, even higher than reclaimable energy from vapor latent heat, hence that is why until nowadays our human beings still no hope of massively developing atmosphere latent energy with such an infeasible heat sink unless other breakthrough method is found.

In other aspect, the freshwater resource is so important to the sustainable development of human beings. Specially, for the residents in desert or marine zone, freshwater does matter for their surviving.

Although the commercialized desalination equipment is available in market, but its price and energy consumption is only oriented by corporate use, obviously not affordable to household use for general public living in marine environment.

By scavenging latent heat from air moisture, simultaneously freshwater can be collected effectively [2] [3] [4]. If such a revolutionary invention is ready, that will herald a new era forthcoming with abundant renewable energy and freshwater in every corner of Earth.

§16. Conclusion

Cooking our Earth, the Sun constantly deposits huge energy into the seemingly feeble natural aerial water vapor.

It is a waste of energy and even can cause terrible flood disaster if uncontrolledly let it be in natural water circulation by lightening and raining storm in the **Great Nature** own pace and schedule.

Cherish it and develop new technologies to harness then harvest energy from it, because it is really an undeveloped great energy mine available anywhere and anytime all over the world!

Reference

1. **Phase transition luminescence in boiling water; Evidence for clusters** by W.R. Potter, J.G. Hoffman, Volume 8, Issue 4, December 1968, Pages 265–270
2. **System and modality to generate power from liquid jet in heat engine and more** US 14/564,711, US2016-0160477A1.
3. **System and method to scavenge latent heat and freshwater from air and more** US14/555,378.
4. **Apparatus of quasi-laser induced by vapor condensation and 2 thermodynamic cycling methods,** US14/245,397.
5. **Analysis of a solar-assisted ejector cooling system for air conditioning**, by Int. J. Low-Carbon Tech. (2009) 4(1): 2-8.doi: 10.1093/ijlct/ctn001, first published online: January 1, 2009.
6. **Collector selection for solar ejector cooling system**, by Solar Energy, Elsevier Science Ltd., Vol. 64, Nos 4–6, pp. 223–226, 1998. 1998.
7. **Supersonic nozzle flow in the two-phase ejector as water refrigeration system by using waste heat,** by 9th international conference on heat transfer, Fluid Mechanics and Thermodynamics 2012 [152], Journal of Physics: Conference Series 433 (2013) 012018 doi:10.1088/1742-6596/433/1/012018 / The Irago Conference 2012 IOP Publishing.
8. **Thermodynamic performance of a combined power and ejector refrigeration cycle**, World Academy of Science, Engineering and Technology Vol:7 2013-07-20.
9. **Steady-state analysis of the solar-driven ejector refrigeration system using water, methanol, ammonia as a refrigerant,** International Journal of Emerging Technology and Advanced Engineering, website: www.ijetae.com (ISSN 2250-2459, Volume 2, Issue 9, September 2012).
10. **A comparative performance of Freon ejector refrigeration systems,** 1990 international refrigeration and air conditioning conference.
11. **A 1-D analysis of ejector performance,** by International Journal of Refrigeration 22 (1999) 354–364.
12. **Review of solar refrigeration and cooling systems,** Energy and Buildings volume 67 (Dec 2013) pp 286–297.