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Evaporation channel consumes hundred times more solar power than the winds over the globe

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ABSTRACT

The free convection of the water and air over the globe induces evaporation of standing water and the generation of wind, respectively. The ratio of the corresponding heat transfer coefficients is shown to be equal to the ratio of solar power going into evaporation/precipitation and into wind generation. The present work provides a justification for the estimate on wind power reported by M. King Hubbert and also that wind generation on a global scale is about two-order magnitudes less than the solar power responsible for rainfall. This paper resolves the existing ambiguity in the estimates of wind power over the globe.

***Keywords*:** Free convection, water, air, earth, solar power, evaporation, rainfall, wind

1. INTRODUCTION

The two well known fluids water and air generate natural convections over the globe and cool it. The former causes evaporation of water and subsequent rainfall while the latter generates the wind. The ratio of the corresponding heat transfer coefficients is shown to be equal to the ratio of solar power going into evaporation/precipitation and wind channels. The present work provides a justification for the first time to the observations made by M. King Hubbert (Lapedes 1976) that wind generation on the globe is $Q_{WIND}^{Hubbert} = 370 \cdot 10^{12}$ W and is about two order magnitudes less than solar power responsible for the rainfall ($Q_{Evaporation} = 40000 \cdot 10^{12}$ W) for the benefit of students and teachers of physics.

This paper also resolves the existing ambiguity in the reported estimates of wind power over the globe.

Convection is the name for a means of heat transfer, as distinguished from conduction and radiation. It is the transfer of energy in a liquid or gas by the actual transfer of higher-temperature fluid from a higher-temperature region to a lower-temperature region. If a heated plate were exposed to ambient room air without an external source of motion, a movement of the air would be experienced as a result of the density gradients near the plate. This is called *natural* convection as opposed to *forced* convection, which is experienced in the case of the fan blowing air over the plate. The density gradient gives rise buoyancy forces in the fluid due to the presence of gravity, although gravity is not the only type of force field that can produce the free-convection currents; a fluid enclosed in a rotating machine is acted upon by a centrifugal force field, and thus could experience free-convection currents if one or more of the surfaces in contact with the fluid were heated at the contact point through conduction. As there is no consumption of power which drives a pump or rotates a compressor or blower it almost invariably proceeds in a quiet fashion. Because of these reasons heat transfer coefficients in natural convection are low typically by an order of magnitude compared to the cases involving forced convections.

It will be worth quoting here couple of examples involving natural convection.

- Boiling water - The heat passes from the burner into the pot, heating the water at the bottom by conduction. Then, this hot water rises and cooler water moves down to replace it, causing a circulation pattern.
- Sinking water. A cube of ice on the surface of normal water floats and melts. The melting water being cold having higher density sinks. The less dense water from the sides lifts to fill the vacant space and there by the continuous circulation is formed.
- Evaporation – This also comes under natural convection because the density of water vapour being less dense moves up in the atmosphere taking away the heat thereby cooling the liquid water. The evaporated water eventually condenses and falls over the globe as rain droplets.
- Wind – the generation of air currents due to differential heating over the globe. The hot air being less dense at the equator moves up and the cold dense air from North and South poles comes in to occupy the space forming a circulation pattern.
- The Earth's Convection - The Earth's mantle moves very slowly due to the convection currents beneath the surface. These currents transfer heat from the Earth's hot core, sending them up to the surface. The swirling currents cause the tectonic plates to move very gradually around the planet's surface.
- Ocean surface current - Ocean surface currents are driven by a process called expansion. The climate at the equator is hot all year long and warms the ocean surface. This makes the surface water expand so that the water level is a little higher at the equator. The force of gravity causes the expanded surface water to slide toward the North and South poles. This effect helps to drive the surface ocean currents.

In all the examples of convection process a circulation pattern is formed due to the cold fluid from the sides coming to occupy the place generated by the movement of hot fluid. This causes a steady-state velocity distribution and a temperature distribution. Furthermore, there is also a steady-state pressure distribution. These stationary conditions will give rise to velocity and temperature as functions of the place only in coordinates x, y and z and not function of time. These distributions will depend on the dimension and shape of the hot body, on its temperature T_S, on the temperature of the surroundings T_∞ at a considerable distance, and on such properties of the surrounding fluid as its viscosity, the coefficient of heat conductivity, the coefficient of cubic expansion and the specific heat. Moreover, the convection depends on the acceleration due to gravity without which the natural convection would be totally absent. A general solution of the differential equations for the three steady-state distributions mentioned above corresponding to three coordinates is not known, because the equations governing the fluid motion are too complicated. It is then customary to compare similar situations, so that the many governing quantities may be assembled in certain combinations, called characteristic numbers, on which the phenomenon depends. This way the problem is greatly simplified, because it now depends on these characteristic numbers only, instead of on many individual variables, couple of the well known characteristic numbers are Nusselt number, Rayleigh number, Reynolds number, Grashof number, and Pandtl number describing respectively, efficiency of heat transfer through convection over conduction, how vigorous the convection may be, the streamline and turbulent motion of the liquid, the ratio of the buoyancy to viscous force acting on a fluid, and the heat transfer between a moving fluid and a solid body.

2. THEORY

The present paper is concerned with the two convection processes on the Earth; the evaporation of water from the ocean surface as it is being heated by solar energy and heating of air lying above surface of the Earth. The expression for convective energy flux q from the surface of the Earth can be written

$$q = h(T_S - T_\infty), \tag{1}$$

where $T_\infty < T_S$ is the temperature of the fluid beyond the surface where the temperature does not sensibly change, and h is the convective heat transfer coefficient which is often written as a power law in terms of Rayleigh number:

$$h = \frac{\kappa}{L} C(GrPr)^m, \tag{2}$$

Here L is the characteristic linear dimension of the cooling object, and κ is the thermal conductivity of the surrounding fluid. The dimensionless Grashof number Gr and Prandtl number Pr are, respectively

$$\mathrm{Gr} = \frac{g\beta\Delta TL^3}{\nu^2}, \ \mathrm{Pr} = \frac{\rho c_P \nu}{\kappa} \tag{3}$$

where c_P is the specific heat per unit mass, ρ is mass density, ν is kinematic viscosity, C is a dimensionless constant that depends on shape and orientation of the object, m is an exponent determined by experiment or theory, g is the acceleration due to gravity, β is the volume coefficient of thermal expansion, and ΔT is the temperature difference between the Earth and its surroundings. The product $GrPr$ is the dimensionless Rayleigh number

$$Ra = GrPr = \frac{g\beta\Delta TL^3\rho c_P}{\nu\kappa} \tag{4}$$

If the Rayleigh number which is associated with buoyancy-driven flow is below a critical value for that fluid, heat transfer is primarily in the form of conduction however, in case it exceeds the critical value, heat transfer is mainly in the form of convection. The Grashof number is the ratio of the product of inertial and buoyancy forces (per unit mass) to viscous force squared in a fluid, whereas the Prandtl number is the ratio of momentum diffusivity (viscosity) to thermal diffusivity $(\kappa/\rho c_P)$.

Table 1. Thermal and physical characteristics of the fluids water and air (Byalko 1997, Holman 2010 p-658,662).

Characteristic	Air	Water
Thermal conductivity κ	0.02624 J $\mathrm{m^{-1}s^{-1}K^{-1}}$	0.631 J $\mathrm{m^{-1}s^{-1}K^{-1}}$
Coefficient of thermal expansion β	$0.00335\ \mathrm{K^{-1}}$	$0.000214\ \mathrm{K^{-1}}$
Kinematic viscosity ν	$15.69 \cdot 10^{-6}\ \mathrm{m^2\ s^{-1}}$	$0.934 \cdot 10^{-6}\ \mathrm{m^2\ s^{-1}}$
Mass density ρ	$1.1774\ \mathrm{kg\ m^{-3}}$	$995.8\ \mathrm{kg\ m^{-3}}$
Specific heat per unit mass c_P	$1.0057 \cdot 10^3$ J $\mathrm{kg^{-1}K^{-1}}$	$4.179 \cdot 10^3$ J $\mathrm{kg^{-1}K^{-1}}$

Craig F. Bohren (2011) has used this philosophy to compare the cooling rate of a human being of height around one meter in water to the case when he is standing in the air. For fixed $g, L, C, and\ \Delta T,$ the ratio of heat-transfer coefficient in water to that in air, he finds

$$\frac{h_w}{h_a} = \left(\frac{k_w}{k_a}\right)^{1-m}\left(\frac{c_{pw}}{c_{pa}}\right)^{m}\left(\frac{\rho_w}{\rho_a}\right)^{m}\left(\frac{\nu_a}{\nu_w}\right)^{m}\left(\frac{\beta_w}{\beta_a}\right)^{m} \tag{5}$$

In the present paper this expression will be evaluated for the convection of these two fluids over the globe. It will be shown that this ratio is equivalent to the ratio of solar power going into evaporation and wind channels quoted by M. King Hubbert. Furthermore, for the first time a justification will be provided to the observations made by Hubbert that wind generation over the globe is $Q_{WIND}^{Hubbert} = 370 \cdot 10^{12}$ W and it is about two order magnitudes less than solar power responsible for rainfall. The present paper also resolves the ambiguity in the estimates of wind power over the globe; according to M King Hubbert [Lapedes 1976] its value is $Q_{WIND}^{Hubbert} = 370 \cdot 10^{12} W$ which is the lowest amongst the available projections; Gordon and Zarmi [1989] arrive at a value $Q_{WIND}^{Gordon} = 8700 \cdot 10^{12} W$, Barranco-Jimenez and Angulo-Brown [1996] predict $Q_{WIND}^{Barranco} = 3600 \cdot 10^{12} W$, and Heinrich Hertz [Mulligan and Gerhard Hertz 1997] and Romer [1985] have reported estimates as $Q_{WIND}^{Heinrich} = 4000 \cdot 10^{12} W$, and $Q_{WIND}^{Romer} = 2000 \cdot 10^{12} W$, respectively.

3. HEAT-TRANSFER COEFFICIENTS FOR WATER AND AIR OVER THE GLOBE

The above mentioned philosophy can be extended to the case of the Earth where both water and air are using solar energy to generate natural convections and thereby cooling the Earth. The ratio of the corresponding heat transfer coefficients can be determined through the expression (5) which depends upon the properties of the fluids as well as the exponent m . This exponent may be either $1/4$ or $1/3$ depending on the magnitude of Rayleigh number vide (4). For the object the Earth which is being cooled the characteristic length L is taken to be the radius of the Earth. Also the temperature of the Earth is considered to be uniform throughout around $288\ K$ (De Vos 1992) and that the convection processes occur within the troposphere having upper layer temperature around $227\ K$ yielding $\Delta T = 288 - 227 = 61$ K (Agrawal 2012). The values of Rayleigh numbers for water and air can now be estimated as

$$Ra\ (water) = GrPr = \frac{g\beta_w \Delta T L^3 \rho_w c_{Pw}}{\nu_w \kappa_w} = 2.40 \cdot 10^{32} \qquad (6a)$$

$$Ra\ (air) = GrPr = \frac{g\beta_a \Delta T L^3 \rho_a c_{Pa}}{\nu_a \kappa_a} = 1.50 \cdot 10^{30} \qquad (6b)$$

Since Rayleigh number is greater than 10^7 for both fluids the exponent $m = 1/3$ and the dimensionless constant $C = 0.15$ for the geometry (Holman 2010 p-334) where upper surface is heated - a case similar to the Earth whose surface is heated by solar radiation. Now, one can evaluate ratio of free convection heat-transfer coefficients for water to that of air (Table 1) over the globe. This comes out to be

$$h_w / h_a \approx 127 \qquad (7)$$

As mentioned in the beginning the heat transfer causing convection of water results in its evaporation which subsequently precipitates on the globe (Mulligan and Hertz 1997, Agrawal 2013) may be at some other locations in the atmosphere. The ratio h_w/h_a will be equivalent to ratio of solar power going into the evaporation and wind channels. M. King Hubbert (Lapedes 1976) has given the division of the intercepted solar energy $1.74 \cdot 10^{17}$ W over the globe into various channels as follows:

Direct reflection into the space, $Q_{Albedo} = 52000 \cdot 10^{12}$ W

Direct conversion into heat, $Q_{Heat} = 82000 \cdot 10^{12}$ W

Evaporation and precipitation, $Q_{Evaporation} = \ \ 40000 \cdot 10^{12}$ W (8)

Winds, waves, convection & currents, $Q_{Wind} = \ \ 370 \cdot 10^{12}$ W

Photosynthesis, $Q_{Photosynthesis} = \ 40 \cdot 10^{12}$ W

The ratio of our interest $Q_{Evaporation}/Q_{Wind} \approx 108$ matches very well with the present calculation $h_w/h_a \approx 127$. The power $Q_{Evaporation} = \ \ 40000 \cdot 10^{12}$ W gives an average annual rainfall of about one meter over the globe (Mulligan and Hertz 1997, Agrawal 2013). Since, this is true as per the records published by UNESCO (Chow 1988) hence; the solar power going into wind $Q_{WIND}^{Hubbert} = \ \ 370 \cdot 10^{12}$ W proposed by Hubbert must also be true. The present work, therefore, provides a justification for the first time to the observations of M. King Hubbert that the magnitude of wind generation on the globe is $Q_{WIND}^{Hubbert} = \ \ 370 \cdot 10^{12}$ W and it is two order magnitudes less than the power going into evaporation channel. The other estimates [Barranco-Jimenez and Angulo-Brown 1996, Gordon and Zarmi 1989, Mulligan and Gerhard Hertz 1997, Romer 1985] for wind power available in the literature are order of magnitude higher than this.

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