The Atmospheric Vortex engine
IEEE-STH symposium presentation notes

Slide 1 – AVE the Future

1. AVE stands for Atmospheric Vortex Engine. In Latin AVE means “HELLO”. Hello everyone and welcome to our Energy Future.

2. As an engineer I was aware that more work is produced by the expansion of a warm gas than is required to compress the same gas after it has been cooled and realized that this kind of process had to be responsible for the energy of tornadoes.

3. An Atmospheric Vortex Engine is a machine for producing a controlled vortex and for using the vortex to capture the mechanical energy produced when heat is carried upward by convection.

4. This photo of a cooling tower has been touched up to show what the future Atmospheric Vortex Engine will look like.

Slide 2 – AVE drawing

1. The lower half of this drawing shows a side view of an AVE; the upper half of the drawing shows a plan view.
2. The vortex is formed by admitting warm air in a circular arena via tangential entry ducts causing the air to spin about the vertical axis.
3. The air is heated or humidified in heat exchangers located upstream of the tangential entries.
4. The heat source can be solar energy or waste industrial heat. The solar energy can be: warm sea water, or warm humid air.
5. The energy is produced in peripheral turbines. An AVE is a large power source and could produce 100 to 500 MW of electrical energy.
6. An AVE station could have a diameter of 150 m and a height of 100 m. The vortex could have a diameter of 30 m and extend to a height of 15 km.
7. The rising air behaves like a spinning top; there is little loss of angular momentum in the 30 minutes of so required for the air to rise from the bottom to the top of the troposphere.
8. The vortex does not need to rise vertically. If the vortex is broken up by a gust of wind it reforms with warm spinning air from below. The warm air and the chimney are one and rise together.
9. Air can only enter the vortex in the layer next to station floor where tangential velocity is reduced by friction.

Slide 3 – AVE vs Solar Chimney

1. The thermodynamic basis of the AVE is the same as that of the solar chimney.
2. The solar chimney at the upper left of this figure was built in Spain in the 1980's; it had a chimney 10 m in diameter and 200 m high and an electrical output of 50 kW. It operated very successfully for 7 years.
3. The proposed Australian solar tower at the lower left would have a chimney 1 km high and an electrical capacity of 200 MW.
4. A natural draft chimney is a cylinder in radial compression; at any level the pressure is less inside than outside.
5. The AVE replaces the physical wall of the chimney with centrifugal force. The vortex diameter adjusts itself until radial pressure difference is balanced by centrifugal force.
6. The central panel compares the solar chimneys on the left to the vortex on the right. Efficiency goes up from 0.2%, to 1.5% and to 20% as height go up from 200 m, to 1000 m, and to 10,000 m.

Slide 4 – Solar Chimney

1. Here is a side view of a Solar Chimney. The solar chimney is an extremely simple but extraordinary device. It is the only solar engine capable of producing power from temperature differences of 20℃ and even lower. All other solar engines require solar energy concentrators.
2. In the Spanish chimney the solar collector increased the air temperature by approximately 20℃.
3. To produce the same power a 1000 m high chimney would need a temperature difference of 4℃; a 10 km high chimney would need a temperature difference of only 0.4℃. Providing the chimney effect is high enough there is no need for a solar collector; natural heat sources become sufficient.

Slide 5 - Vortex photos

1. Here are photos of vortices I produced in 2008. The tangential entries and the heat source were in a 1 m high by 4 m diameter base unit located under the transparent cylinder. You can see top of the base unit in the photo on the right.
2. The vortex was made visible with smoke emitters. The visible vortex extended 3 m in the Lexan cylinder and then up to 15 m in the free atmosphere.

Slide 6 – Earth's Energy Budget

1. This slide shows the Earth's energy budget. The atmosphere is heated from the bottom by solar radiation and cooled from the top by infrared radiation to space.
2. Heat must be carried upward by convection since most of the heat radiated from the Earth surface is absorbed and radiated back down by greenhouse gases.
3. There is a potential for converting approximately 20% of the heat 102 W/m^2 carried upward by convection to mechanical energy.

Slide 7 – Energy Production Potential

1. This figure shows the energy production potential of the Atmospheric Vortex Engine.
2. The numbers are staggering:
   - The solar energy received by the Earth is 174,000 TW,
   - Global electrical energy production rate is 2 TW and global total thermal energy produced is 15 TW,
   - The heat carried upward by convection in the atmosphere averages 52,000 TW; converting 12% of this heat to mechanical would produce 6,000 TW.
3. The mechanical energy production potential of atmospheric convection is 3000 times our electric energy production and 400 times our total energy production.

Slide 8 – Combined Cycle

1. This diagram shows how an AVE can be combined with a conventional thermal power plant.
2. The brown bottom half of the diagram represents a conventional thermal power plant which reject heat at temperatures close to the temperature at the bottom of the atmosphere, typically 30℃.
3. The green upper half represents the AVE which uses the heat rejected by the conventional plant as its heat source and reject heat to the temperature at the top of the troposphere, typically -60℃.
4. Combining an AVE with a power plant would increase power output by 30%. The AVE increases overall efficiency by reducing cold source temperature from +30℃ to -60℃.
5. Waste heat is the low lying fruit as far as heat source are concerned; the heat is already concentrated and at a temperature typically 10 to 20℃ above the temperature of ambient air.

<u>Slide 9 – AVE Ideal Cycle</u>

1. The AVE or gravity ideal cycle is identical to the Brayton gas-turbine ideal cycle shown in the next slide except that the expansion takes place in vertical conduits instead of in machines.

<u>Slide 10 – Brayton Cycle</u>

1. Here is the Brayton gas-turbine ideal cycle with the same process conditions.
2. In both cycles, the air is heated at a pressure of 100 kPa and cooled at a pressure of 20 kPa.
3. In the gravity cycle the gas expands as it rise and is compressed as it descends.
4. Compressing descending air is far more efficient than compression in a machine; all you have to do is pile more air on top.
5. Once the ideal cycle is understood irreversible cycles can be analyzed by adding the effects of irreversibility such as turbine efficiency, and friction.

<u>Slide 11 – Piston covered air column</u>

1. This piston covered closed insulated thermodynamic system consisting of a column of pure air with uniform potential temperature or entropy was first used by Austrian thermodynamist Max Margules in 1905 to investigate how wind energy is produced.
2. The slide shows that work can be calculated in several ways all giving the identical results:
    a. 1. From the difference between the heat received and the heat given up.
    b. 2. From the heat received multiplied by the Carnot efficiency.
    c. 3. From the total energy equation.
3. The three state process shows that the mechanical energy is produced during lifting process 2-3. The heating can take place before the lifting; the cooling can take place after the lifting.
4. It can be shown that the statement: “Work production is equal to the heat received times Carnot efficiency” remains valid for systems with non uniform entropy and for mixtures of air and water.

<u>Slide 12 – AVE process</u>

1. This slide shows the AVE ideal Process. The overall process consist of three individual processes:
    - Process 1-2: Isentropic expansion in a turbine,
    - Process 2-3: Constant pressure heating and humidification in a wet exchanger,
    - Process 3-4: Isentropic expansion in a vertical tube.

Slide 13 – Calculations results

1. In Column 1: The ambient air temperature and relative humidity were selected to make the work zero to provide a datum.
2. In Case 2 of column 2: The relative humidity of the air is increased to 97% by spraying 26℃ water in the air in a wet cooling tower; approximately 3000 J/kg of work is produced.
3. In Case 3: The temperature of the air is increased to 30.7℃ by heating the air with 36℃ water in a dry heat exchanger during heating process 2-3.
4. In Case 4: The temperature of the air is increased to 33.6℃ by heating the air with 40℃ water in a dry heat exchange upstream of the turbine.
5. In the three cases the work is approximately 3000 J/kg and the efficiency is close to 35%.
6. The table shows that the efficiency calculated as the work produced divided by the heat received is the same as the Carnot efficiency calculated using the temperatures at the bottom and top of the vertical tube as hot and cold source temperature.
7. The use of a wet heat exchange at reduced pressure makes possible the use of low temperature heat sources. The ability to use low temperature heat sources is a major advantage since they are widely available.
8. The energy production potential of maritime tropical air is typically 1000 to 2000 J/kg before heat addition. The energy production potential of continental surface air during periods of heavy insolation can be as high as 5000 J/kg.

Slide 14 – Energy resource comparison

1. Here is a comparison of major energy resources.
2. The heat content of water vapor in the bottom kilometre of the atmosphere is twice the world remaining oil reserves.
3. The heat content represented by a 3° C increase in the top 100 m of tropical waters is 20 times the energy content of the world oil reserves.
4. The sun can replenish the heat content of tropical seas in 100 days.
5. Producing the earth's oil resources took over 100,000,000 years.

<u>Slide 15</u>

1. The blue path is this satellite image shows the cooling effect of hurricane Isabel which occurred in September 2003.
2. Orange represents SST over 30°C; blue represents SST under 27°C. In March the Caribbean was all blue; in August it was all orange; and in September Isabel came through and changed the orange back to blue.
3. There is a huge amount of spray or spume produced in hurricanes. Spray droplets are cooled to their wet bulb temperature and fall back in the sea reducing sea temperature.
4. The cooled water sinks and is replaced by underlying warm water so long as there is warm underlying water. The passage of a hurricane can reduce SST by 3 to 6°C to a depth of 100 m.

<u>Slide 16</u>

1. This slide illustrates how the AVE replicates the waterspout process by spraying warm water in the air increasing its humidity and by then giving the air a spin.
2. A conventional solar power plant to supply a city would require an area 50 to 500 time the area of the city and renders the area unavailable for other uses such as farming. An AVE uses the earth's surface in its unaltered state as the solar collector and does not interfere with other uses such as farming.

<u>Slide 17</u>

1. The Atmospheric Vortex Engine has the potential of providing abundant clean carbon free energy.
2. The sun provides the heat; the atmosphere provides the working fluid; and the vortex provides the conduit.
3. Work is produced when water descends and when heat rises. The AVE creates a river of rising air and captures the energy produced by the process.
4. There is plenty of clean energy produced by the sun in the atmosphere; we just have not yet figured out how to harness it. The energy produced by a large hurricane can exceed the energy produced by humans in a whole year. The energy produced in a large tornado can exceed the energy produced by a large power plant like Darlington.

Supplemental Slides

Slide 18

1. In this atmospheric sounding, the green curve is the temperature of the environment.
2. The blue curve is the temperature of a rising surface air parcel.
3. The red curve is the temperature of an air parcel that received additional heat in a heat exchanger.
4. Work is proportional to the area between the environment curve and the rising air curve.
5. Heated air tends to rise to their level of neutral buoyancy which is normally close to the tropopause which is the low temperature point at the top of the sounding.

Slide 19

1. The green curve on the right is the difference in temperature between the rising air and the environment with no entrainment.
2. The rising air is initially 1 ℃ warmer than the environment. The temperature difference decreases until the condensation level is reached and increases afterward.
3. The curves on the left show the effect of entrainment. Re-evaporation of condensed water cools the rising air. Low relative humidity air (yellow curve) has more cooling effect than high relative humidity air (red curve).
4. The shallowness of fair weather cumulus is due to this evaporative cooling.

Slide 20

1. The temperature of descending air increases at the dry adiabatically lapse rate (red) which is higher than the lapse rate of the environment (green). Radiative cooling (blue) cools the descending air.
2. Radiative cooling move the green curve to the left 1.5 ℃ per day thereby increasing instability.
3. Subsidence moves the green curve to the right. A subsidence of 2000 m would move the curve 6 ℃ to the right.
4. Subsidence occurs where the air is easiest to compress which is where the environment is coolest therefore subsidence tends to take place well away from updrafts.
5. Hurricanes remove huge quantities of heat from the tropical seas. There is little warming of the tropical upper troposphere because the subsidence occurs in high latitudes (Indian summer).

Slide 21

1. The maximum work that can be produced by moving a fluid adiabatically from one position to another can be calculated by applying the total energy equation to an open system.
2. Work only depends on the initial and final condition. There is no need to consider what is going on outside the tube; there is no need to consider density differences as is done in CAPE calculations.

Slide 22

1. A natural draft cooling tower is a mechanical energy producer since it eliminates the need for fan energy.
2. An AVE extends the tower and produces power.

Slide 23

1. Dr. Kerry Emanuel of MIT compared a hurricane to a Carnot engine receiving heat at a temperature of 300 K and giving up heat at 200 K.
2. A hurricane is an irreversible process; the mechanical energy dissipates since there is no machine to take the mechanical energy out of the system.

Slide 24

1. Side view of an AVE with wet heat exchange.

Slide 25

1. Capturing work of convection requires that the expansion take place at constraint in an expander. The expansion must be restrained otherwise the work reverts to heat.
2. This slide uses a cylinder and piston to illustrate a possible energy capturing mechanism. If the automat does not restrain the expansion the work is lost.

Slide 26

1. Capturing the mechanical energy produced when air expands requires that the expansion be restrained
2. There is only so much work required to push the ambient air out of the way the rest of the work stays in the cylinder and reverts to heat.

Slide 27

1. Producing convection energy requires that heat be received at higher pressure than it is given up which is what happens in the atmosphere.