Turbines (Power Generation)

To calculate the potential for energy production from the turbines placed in the solar chimneys we have looked for existing installation that may serve as precedent.

Precedent - Spain

A prototype plant 150 km South of Madrid, Spain produced electrical energy economically for 9 years: http://push.pickensplan.com/group/solarupdrafttower . The project was commissioned by the German Ministery of Research and Technology and built by the German engineers Schlaich and Partners. Only one turbine is used – simple but effective. The collection area consists of 4.4 ha of plastic material called Tetla, polyvinylfluoride. The foil is 0.1 mm thick but can withstand winds up to 150 km/h.

It works not only during the day but also at night and at rainy and cloudy days as the heated ground underneath provides enough energy.

The chimney is some 200 m high and 10 m in diameter. The output was 60 kW at peak and 30 kW average. Cost was about 1,000,000 USD.

Precedent - Australia

EnviroMission is planning to build a 450 m tower in Australia. Solar Tower Technology // Powering Change in Renewable Energy // EnviroMission reduces greenhouse gases. They show a circular greenhouse area with a tower structured as a single pipe. Solar heat radiation warms up the air, which moves upward in the chimney. They give ground air temperature as 86°F (30° C) and the air at the bottom of the tower as 158°F (70°C). At the top of the tower 68°F (20°C) is visible. The greenhouse produces airflow of 49 feet/sec, which drives 32 turbines at the bottom of the chimney generating 200 MW.

Physics

In hydrodynamics, the laminar flow through a pipe of radius R with a pressure difference of Δp between the two ends is

$$dV/dt = ((\pi \Delta p) / (8 \eta h)) R^4$$

This equation is called the Hagen-Poiseuille law or Ohm's law for the laminar flow through a pipe. η is the viscosity of the flowing medium, and h is the length of the pipe. The Hagen-Poiseuille law allows us to derive the average flow velocity v using

$$v = dV/dt (1 / \pi R^2)$$

with the result

$$v = (\Delta p / (8 \eta h)) R^2$$

The average flow velocity is proportional to the square of the radius of the pipe, but the volume transport through the pipe is proportional to the fourth power of R. The mass, and therefore, the energy transported by the pipe, is proportional to the volume flowing through the pipe. If we insert an empirical constant A, which may depend on actual temperatures of the air within the pipe, we can estimate the power produced by a solar updraft tower as

$$P = A\, dV/dt = ((\pi\, A\, \Delta p) / 8\, \eta)\, (R^4 / h)$$

If we assume the actually measured parameters at the Spanish solar power plant, and use the peak power generated P = 60 kW, h = 200 m, and R = 5 m, we can estimate the factor

$$((\pi\, A\, \Delta p) / 8\, \eta)\ (\text{Spain}) = 19{,}200\ \text{W/m}^3$$

Using that number, we can double check with the projected Australian with h = 450 m and R = 50 m, and obtain

$$P\ (\text{Australia}) = 270\ \text{MW}$$

This figure is reasonably (for the simple approach taken here, neglecting collection area size and actual air temperatures) close to their projected power production of 200 MW.

So far, we have an equation, which allows us to estimate the power production of a solar updraft tower of height h and radius R. Although there are several known limitations of the applicability of this equation, we can apply it to Devices # 1 – 5 of LAG, and take the result as an estimate what to expect of the power production of each of the devices.

Device 1 has 60 chimneys with R = 0.5 m and h = 60 m.

$$P\ (\text{Dev 1}) = 60 * 19{,}200\ \text{W/m}^3\ (0.5^4\ \text{m}^4) / 60\ \text{m} = 1.2\ \text{kW}$$

Similarly, Device 2 with 68 chimneys produces
Device 3 with 96 chimneys produces
Device 4 with 121 chimneys produces P (Dev 4) = 2.4 kW
Device 5 with 60 chimneys produces P (Dev 5) = 1.2 kW
The total estimated power produced by all five devices is P (Total) = 8.1 kW

References

1) www.inhabitat.com
2) Design of Commercial Solar Tower Systems – Utilization of Solar Induced Convective Flows For Power Generation, Joerg Schlaich, Rudolf Bergermann, Wolfgang Schiel, Gerhard Weinrebe
3) http://push.pickensplan.com/group/solarupdrafttower . Video about EnviroMission
4) http://push.pickensplan.com/group/solarupdrafttower . Video about Manzanares, Spain