Floating Solar Chimney technology for EU and Mediterranean countries

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Abstract—**The purpose of this paper is to present the Floating solar chimney (FSC) technology and to have the utmost benefits of this technology compared to PVs and CSPs (Parabolic through), that make it the proper candidate for large scale solar electricity generation in the Mediterranean region, and the Desertec project.**
The solar chimney power plants are usually mentined as solar updraft power plants and their proposed solar chimneys are reinforced concrete structures. The Floating Solar Chimney (FSC) is a low cost alternative of the concrete solar chimney. The floating solar chimney power plants, due to their similarity to hydroelectric power plants, were named by the author Solar Aero-Electric Power Plants (SAEPs).

Index Terms—**Floating Solar Chimney, Solar Aero-Electric Power Plant**

I. Nomenclature

α kinetic energy correction coefficient.
Ac solar collector (Greenhouse) surface area in m^2
b Approximate thermal losses coefficient of the greenhouse to the ambient and ground in $W/m^2\ {}^0K$ (per m^2 of its surface area and ${}^0K$ of the temperature difference T_{03}-T_{02})
C_1, C_2, C_3 intermediate algebraic expressions
C_p air specific heat equals approximately to1005 J/Kg ${}^0C$
d floating solar chimney internal diameter in m
g gravity constant equals to 9.81 m/sec^2
G Horizontal irradiance in W/m^2
H floating solar chimney height in m
η_T overall efficiency of the air turbines and generators
k solar chimney internal friction loss coefficient
$\dot{m}$ Warm air mass flow in Kg/sec
p_0 atmospheric pressure at ground altitude
p_4 atmospheric pressure at solar chimney exit
R air constant approximately equals to 287 J/Kg ${}^0C$
ta Average of the product: {overall roof transmission coefficient for solar irradiation X soil absorption coefficient for solar irradiation}
T_0 ambient air temperature in ${}^0K$
T_{02} input stagnation air temperature in the greenhouse in ${}^0K$
T_{03} exit stagnation air temperature from the greenhouse and in the air turbine in ${}^0K$
T_4 exit air temperature at the top of solar chimney
T_4' exit air temperature (isendropic)
w_1, w_2, w_3, w_4, w_5 intermediate calculation coefficients
W_y annual horizontal solar irradiation in KWh/m^2

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II. Introduction

The world is facing a global warming threat due to greenhouse gases and the climate change. Unfortunately there is no consensus between states politicians and academia about the proper technologies, measures and policies in order to prevent it. The energy lobbyists are promoting their clients proposals and technologies while the public opinion is confused. Although the majority tends to believe that the existing technologies can resolve the problems and it is a matter of public spending only, I do not share this optimistic view. My opinion is that there is a missing technology which is necessary in order to encounter the global warming threat. In order for the next generations to avoid climate change Armageddon we should keep the global increase in temperature below 2 ${}^0C$.

Let me explain my pessimistic view. Let us assume that the developing world is binding to any cost of applying a mixture of zero carbon emissions technologies. To my opinion it is impossible that this can be adopted by the underdeveloped world countries, due to high cost and public pressure. Thus the "leakage of CO_2", by the above countries generating electricity activities, is enough for the failure of worldwide efforts.

However I believe that in order to replace coal technologies for electricity generation all over the world we should develop and propose a solar zero emissions technology with the same cost per produced KWh.

Wind turbine technology that recently had a high penetration in electricity generation has a direct production cost very close to coal fired power plants KWh direct production cost. However due to its intermittent electricity generation the wind technology can not offer to the electric grids as much as necessary and at the most favorable case cannot cover more than 45% of electrical power and 20% of electrical energy demand.

In case that the wind technology is equipped with a massive energy storage system its cost is rising high and is losing its cost competitive advantage.

Solar technologies have unlimited production capabilities and at least CSP technologies can be equipped with thermal energy storage systems securing their uninterrupted power generation. Using the existing technology of HVDC transmission lines the generated electricity can be transmitted to the demand areas.

However there is a problem, their KWh direct production cost is four times more expensive than the coal KWh. That is why they have marginal application in special places or in countries with high incentives or subsidies in their favor till now.

The other two options are the nuclear power plants and the coal fired power plants with carbon capture and storage.

Even if the decisions for such technologies were magically supported by the majority of the political parties, the public opinion and the local communities at the places of their installation, due to complicated technological and legal matters should they arise, their large scale implementation it could last for decades.
My proposal is related to a low cost alternative of solar updraft tower technology named Floating Solar Chimney (FSC) technology.
FSC technology is the appropriate solar technology that can replace fossil fueled technologies for large scale electricity generation. The main reasons are:
a. FSC technology is cost competitive. This means that FSC technology can generate electricity with a direct cost per produced KW close to coal fired KWh.
b. The FSC technology is operating continuously (24x365) thus it can replace coal fired base load power plants.
c. The technology demands no water for its operation.
d. The power plants of the FSC technology are made of recyclable existing material in the market and their deployment on site can be done very quickly.
Using FSC technology on a 3% of desert or semi desert areas of our planet, with only an 1% efficiency, we can generate at least 50% of our present and future electricity demand.

III. Floating Solar Chimney Technology Principles of Operation

A solar chimney power plant is made of three major components:

- A large solar collector, that is made of a transparent roof supported a few meters above the ground (the greenhouse). The transparent roof can be made of glass or crystal clear plastic. The greenhouse is open in its periphery so that ambient air can move freely in it.
- A tall cylinder (the solar chimney) placed in the center of the greenhouse that is up drafting the warm air of the greenhouse, due to its buoyancy. The solar chimney has been proposed by Shlaight [1]-[2] as a reinforced concrete structure. A low cost alternative of the concrete cylinder structure, is the floating solar chimney. It a lighter than air structure and has been proposed by Papageorgiou [10]-[11]-[15], in order to lower their PPs construction costs.
- And a set of air turbines geared to appropriate electric generators (the turbo generators), placed on horizontal axis in a circular path around the base of the solar chimney or with vertical axis inside the entrance of the solar chimney.

The air turbines could be two stage machines i.e. with a stator of a set of inlet guiding vanes and a rotor of several blades Gannon A., Von Backstrom T.W. [4]. The gear boxes are adjusting the rotation speed of the turbines to the generator rotation speed defined by the grid frequency and their pole pairs Papageorgiou [13].
The up drafting air mass flow is offering a part of its energy to the air turbines that are rotating the geared electric generators, which are transforming the rotational mechanical power to electrical power.

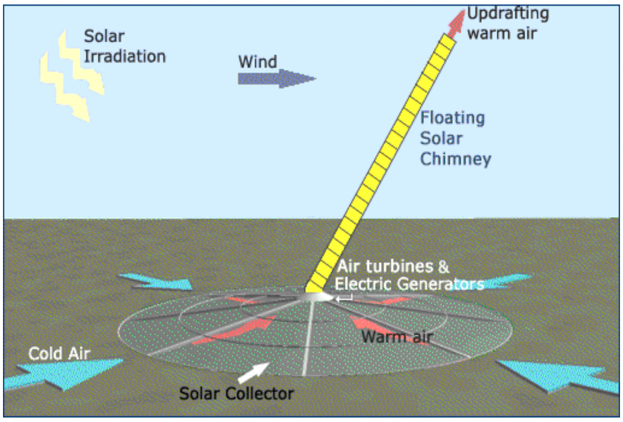

Fig 1.Floating Solar Chimney Power Plant in operation

Thus the first two components of the floating solar chimney power plants form a huge thermodynamic device, up drafting the ground ambient air to the upper atmosphere layers and the third component is the electricity generating device operating by the moving air mass.
The solar irradiation is offering thermal power

$$P_{Th} = \dot{m} \cdot c_p \cdot (T_{03} - T_0)$$

to the up drafting air mass flow $\dot{m}$ of the ambient air.
This thermal power is transformed to air kinetic power at the exit of the solar chimney P_{Kin} plus the friction thermal losses inside the solar chimney P_{Fr}, plus mechanical rotational power P_{Mech} on the air turbines plus thermal losses P_L to the turbo generators.
An indicative figure of a solar chimney Power Plant with a circular solar collector and a Floating Solar Chimney inclined under external winds is shown in (1).
An excellent thermodynamic study of solar chimney power plant operation was presented by Gannon A. & Von Backstrom T.W. in [2]-[3].
The annual efficiency of the FSC PP was studied by Papageorgiou in [12] .
The ground thermal storage effect has been studied by Bernades M.A. dos S., Vob A., Weinrebe G. [5] and Pretorius J.P., Kroger D.G. [6].
Pretorius J.P presented his PhD dissertation on the subject in 2007 [14]. The most important results of [14] are that the solar chimney power plant's annual power production can be increased up to 50% using a second glazing below the outer glazing and its output power production is affected by the ground roughness and ground solar irradiation absorption coefficients.

IV. Operational Characteristics

Following the approximate analysis of appendix I, for the average day of the year and for a SAEP of given dimensions (Ac=Greenhouse area in m^2 and d=internal diameter of the Floating Solar Chimney in m) for a SAEP with a double cover roof that is going to be installed in a place of annual horizontal solar irradiation Wy in KWh/m^2 the diagram relating the annual efficiency of the SAEP to its FSC height H can be calculated.

The following figure (2) shows the annual efficiency for a SAEP of Ac=100Ha ($10^6 m^2$), d=40m and Wy=1700 KWh/m^2 (Cyprus).

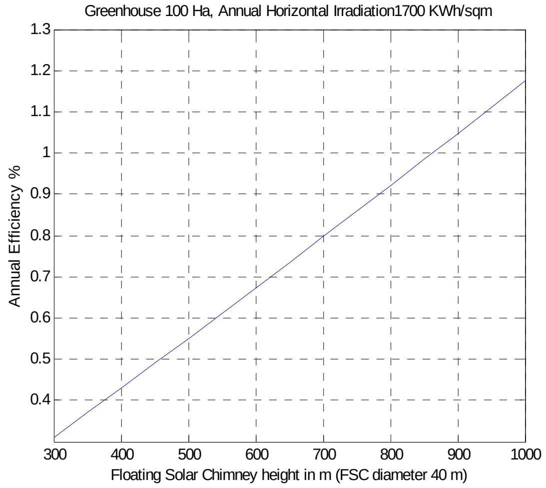

Figure 2. Annual efficiency of a SAEPP as function of its FSC height

As annual efficiency it is defined the annual electricity generated by the SAEP as % part of the amount of horizontal solar irradiation that is arriving at the greenhouse's roof. As an important remark we should notice that if the greenhouse has a single cover the efficiency will be lower by 35%.

With a more elaborating analysis the daily profile of the electricity generation can be calculated. In a yet unpublished research of the author a code has been produced by which a 24 hour power production curve can be calculated. In the following fig(3) the 24 hour electricity generation profile of the previous SAEP for an average day of the year is shown. In the diagram the daily solar irradiance is given (sun is rising at 6.00 AM and goes down at 18.00 PM), together with two electricity generating profiles.

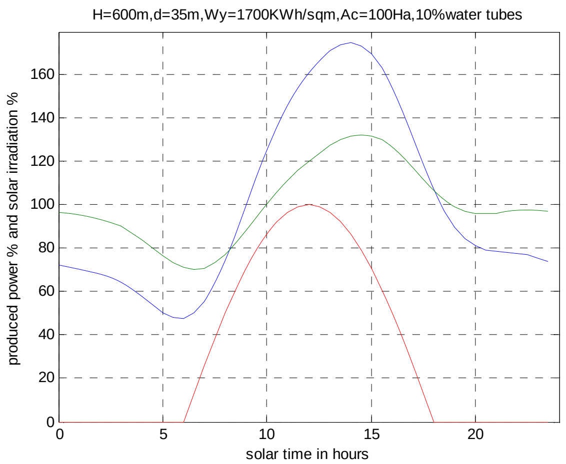

Figure 3. Typical daily production curves of the SAEP (blue ground only and green 10% of its ground covered by 35 cm water tubes)

The less smooth profile shows the power when only the ground acts as a thermal storage means. While the smoother profile is achieved when the greenhouse is partly covered (~10%) by tubes of 35cm of diameter filled with water, i.e. there is also additional artificial thermal storage. Both profiles show that the SAEP is operating 24 hours/day, due to the greenhouse thermal storage.

That is a considerable benefit of the FSC technology compared to the rest of solar technologies and wind technology which if are not equipped with an energy mass storage system they can not operate continuously.

With a limited (~10%) of the greenhouse ground covered by plastic tubes (35 cm) filled with water, the maximum daily power is approximately 125% of its daily average, or the average is 80% of its maximum. Taking into consideration the seasonal power alteration and assuming that the maximum daily power in summer is at a typical place approximately 70% of the average daily power production, the average annual power can be estimated as a percentage of the maximum power production (at noon of summertime) as the product of 0.80x0.70=0.56.

The maximum power is equal to the rating of the power units of the SAEP (Air turbine, electric generator, electric transformer etc.), while the average power multiplied by 8760 hours of the year defines the annual electricity generation. Thus the capacity factor of a SAEP unit with a moderate artificial thermal storage is ~56%.

In order to find the annual energy production by the SAEP we should multiply its rating power by ~4800 hours. However we should take into consideration that the SAEP is operating continuously (24x365) with a daily and seasonal varying profile.

V. Construction Details of FSC Power Plants

In order to make a rough estimation of the construction direct cost of a floating solar chimney power plant some construction details are necessary.

The greenhouse used just to warm the ground beneath it and the moving air mass $\dot{m}$ through it, does not necessarily have the usual form of greenhouses where special farming or hydroponic activity takes place. We can design something simpler and less expensive. For example its shape could be rectangular, as the usual land fields are. We can also follow the ground elevation and put the FSC on the upper part of the land. The greenhouse could be made as a set of parallel series of reverse V transparent tunnels of panels. All above parallel series of tunnels composed of above panels can slowly elevate, following the ground physical inclination and heading their warm air moving mass into a closed corridor of appropriate dimensions leading to the entrance of the FSC.

The cost of such panels per ground m^2 could be as low as 5.0 EURO. The open corridors beside the panel series can be used for cleaning and maintenance of the greenhouse. An estimated cost for the placing the panels on the ground and raising the terminal corridor heading to the FSC entrance is 1.0 EURO/m^2.

Thus a greenhouse of an active surface area Ac of 10^6 m^2, will have an estimated cost of no more than 6 million EURO. The overall area of the greenhouse should be increased by no more than 10%. This is attributed to the fact of cleaning and maintenance corridor.

An indicative animation of the lower part of a Floating Solar Chimney is shown in the following figure (4).

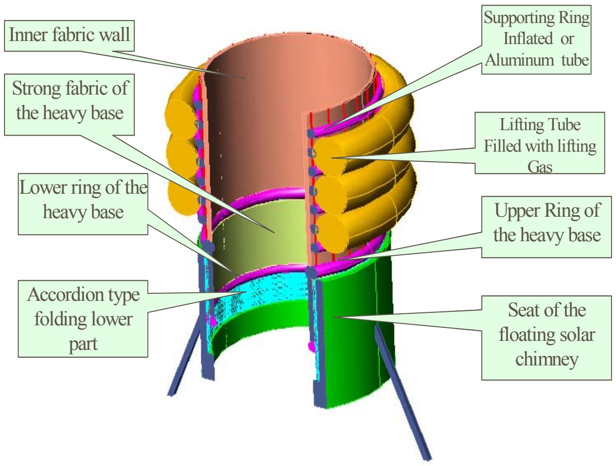

Figure 4. An indicative presentation of the Floating Solar Chimney

A small portion of the fabric structure of the lighter than air Floating Solar Chimney is shown in next fig(5)

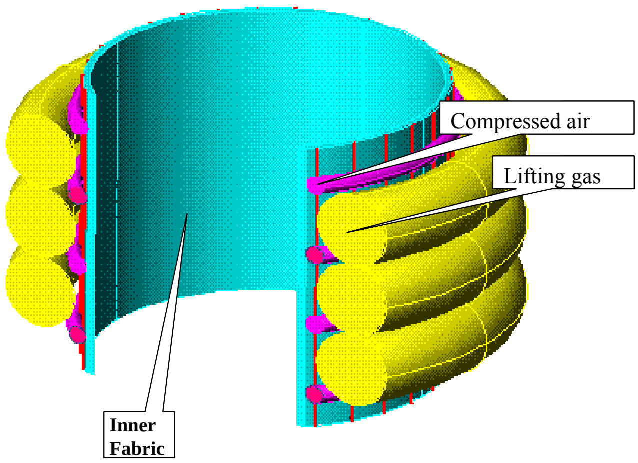

Figure 5. An indicative presentation of a small portion of the fabric structure of the Floating Solar Chimney

The inner fabric and the compressed air tubes, used in order to keep the shape of the FSC, are made of special fabric used already in exterior tent constructions. Their buying cost in large quantities could as low as 4 EURO/m^2. The lifting balloon tubes can be made of special plastic film, mylar for example. Their price for a reasonable thickness is not more than 0.2 EURO/m^2.

Taking into consideration the construction cost of the upper fabric part and its raising cost on site, the fabric part cost of the FSC can be estimated by the formula 50Xd(m)XH(m) in EURO. If we add the cost of the base, the accordion and the seat of the structure the FSC's cost can be estimated by the figure 80Xd(m)XH(m) in EURO.

The electricity generating portion is composed of a set of the air turbines, the gear boxes, the electric generators and the electric transformers plus cabling and switchgears. Taking into consideration the existing figures for the electricity generating part of wind turbines an estimating figure for the overall cost of the turbo generators of the FSC power plants can be estimated by the formula 300X(Rating KW) in EURO.

VI. Construction Cost per Produced GWh of the FSC Technology Power Plants

The construction cost of the respective floating solar chimney power plant can be calculated just as the previous analysis data:

- Greenhouse construction cost 6 EURO/m^2
- FSC construction cost 80XdmXHm in EURO
- Turbo Generator construction cost Rating Power (RP) in KWX300 EURO (RP≈ Annual production/4500 h)
- Various unforeseen plus +10% on the overall cost

In the following figure (6) the construction cost of a FSC power plant with a greenhouse of 1 square Km and a FSC of internal diameter 40m per produced GWh per year has been calculated as a function of FSC's height H. The place of installation of the FSC power plant is receiving a horizontal irradiation of 1700 KWh/m^2 annually (Cyprus and Spain, Greece, Italy and Turkey at their southern regions).

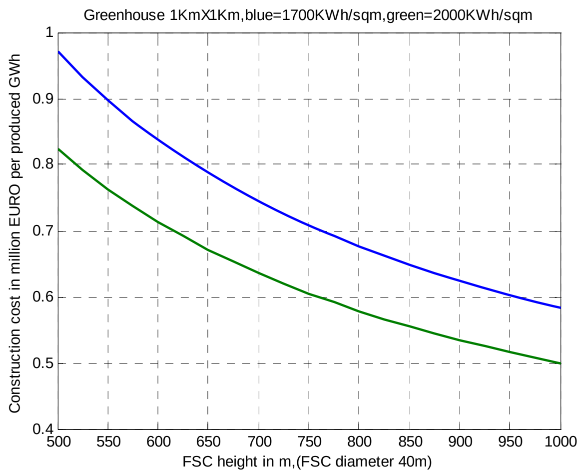

Figure 6. Construction cost of a FSC Power Plant per annual produced GWh as function of its Floating Solar Chimney height

Thus the FSC technology power plants have a much lower direct construction cost compared to the rest solar technologies as follows:

- From 0.6-1.0 million EURO per produced GWh/year in places of annual horizontal solar irradiation 1700 KWh/m^2 (Cyprus and Southern Spain, Portugal, Greece, Italy and Turkey)
- From 0.50-0.85 million EURO per produced GWh/year, in MENA area where the horizontal solar irradiation can be an average of 2000 KWh/m^2

Beyond that the FSC technology has the following benefits compared to the rest solar technologies:

- Operates continuously 24X365 due to its natural thermal storage system
- Demands no water
- Although demands more land per produced GWh, most of the land beneath the greenhouse (if it is a fertile land) can be used for greenhouse farming with the greenhouse properly modified.

However we should say that FSC technology has not yet been tested at a demonstration of a few MW SAEP, in order to prove its viability and construction cost.

VII. Direct Production Cost by Solar Technologies

The direct production cost of all the renewable technologies, not using any fuels, is a sum of three major figures:

- Capital cost that represents in general the repayment cost of a loan equal to the investment of the project, that is approximately equal to the construction cost of the plant, in market interest rate for the period of its depreciation.
- Operation cost, including land lease and license fees
- Maintenance cost including the cost of intermediate replacements of worn materials and equipments

Using data of existing operating solar power plants the Operation and Maintenance (OM) cost per produced KWh is in the range of 1-2 EURO cents.
Under reasonable estimations, including the replacement of fabric parts of the FSCs for every 5 years, the OM cost for FSC technology is near to 2 EURO cents per produced KWh.
The following data were released by PPC investment plans for solar technologies in Greece.

<u>PPC Renewables: Data for new solar projects</u>

<u>Ptolemaida CSP Plant :</u>
- Power Output: 50 MW
- Estimated Annual Electricity Generation : 170 GWh
- Technology: CSP Troughs
-Storage Capacity: 71/2 hours daily
-Storage Technology Method: Molten Salt
-Construction Period: 30 months
-Capital Expenditure: 400 € MM

<u>Megalopolis PV plant</u>
-Power Output: 50 MW
- Estimated Annual Electricity Production: 60 GWh
-Technology: Crystalline panels
- Construction Period: 24 months
- Capital Expenditure: 200 MM €

The depreciation period for the three major solar technologies (PV, CSP, SAEP) for calculation reasons only has been received approximately 25 years and a fair market value for interest rates in such secured income public interest projects it is not more than 6%. This means that the annual repayment (capital return plus interest) is a figure of 7.83%.
Using the above figures of construction cost per produced GWh for the two tested solar technologies and an operation and maintenance cost of 1-2 EURO cents/KWh, the direct production cost of KWh is as follows:

- PVs above 27-28 EURO cents/KWh
- CSP above 19-20 EURO cents/KWh

The following table summarizes the data of the most important solar tested technologies

Technology	Investment cost per KW and per Produced KWh/year	Major Problems for Large scale application
PV	4000 EURO/KW (1200 hours of operation on rating power) gives ~3.3 million EURO/ (GWh/year)	-Very high investment cost per produced KWh/year -Non continuous electricity generation
CSP (parabolic through with Thermal Storage System)	8000 EURO/KW (3400 hours of operation on rating power with TES) Or ~ 2.3 million EURO/ (GWh/year)	- High investment cost per produced KWh/year - Demands 15% gas - Demands a lot of water for its operation

If we use the construction cost figures produced for the FSC Power Plant of 1 square Km plus 2 EURO cents /KWh for OM, we have the following data:

- For South Europe 6.7-9.8 EURO cents/KWh
- For MENA area 6.0-8.7 EURO cents/KWh

The lower figures are for FSCs of height H=900m and the higher for FSCs of height H=500m.
Thus the direct production cost of electric KWh by the FSC technology can be 3-5 times cheaper than the other two major tested technologies.
Thus I believe that the FSC technology should be tested as soon as possible, taking into consideration that its direct production cost of KWh is close to fossil fueled KWh direct production cost without any CO_2 emissions penalties. If we add up such penalties, FSC technology is far cheaper than fossil fueled power plants per produced KWh.

VIII. Conclusion

The FSC technology has been presented and its direct production cost of electricity KWh was estimated. A comparison between the already tested solar technologies (PVs and CSPs) and that not yet tested FSC technology has proved that FSC technology is superior in every aspect. Furthermore FSC technology due to its operational characteristics and its low direct production cost of KWh can replace conventional fuel consuming electricity generating technologies.
The FSC technology is the proper solar technology for large scale application in Mediterranean countries, especially in MENA area countries. A 40% of the electrical energy demand of EU can be produced by FSC technology power plants in North Africa and can be transferred to the EU with UHVDC transmission lines. This is mentioned as the Desertec project supported by French president Nicolas Sarkozy with his political initiative for a closer cooperation of MENA countries and EU (EUROMED).
For Cyprus the FSC technology is an ideal solution for a large scale application on the island. Using an area of 12KmX12Km an amount of 1500-2500 GWh of zero emissions electricity can be generated annually. If the land beneath the greenhouses of the FSC power plants is fertile most of it can be used for greenhouse farming.

IX. Appendix I

An approximate procedure for the derivation of the equation describing the operation of the SAEPP i.e. the electric Power Output P as function of the moving air mass flow $\dot{m}$ has been proposed by the author in ref [6].

Using the thermodynamic cycle analysis as shown in the following figure (8)

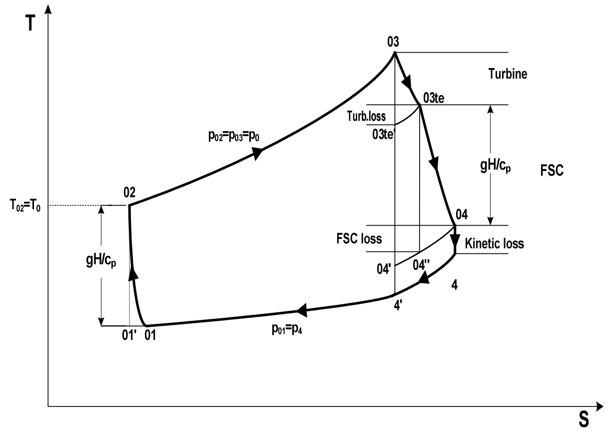

Fig 8

A short presentation of the results of this analysis is given as follows:

The derived equation by the analysis for power output P (in Watts) is the following:

$$P = C_p \cdot \dot{m} \cdot \left(T_{03} - C_1 - T_4 - C_2 \cdot T_4^{\ 2} \right) \quad \text{where:}$$

- T_{03} (in ^{0}K) is the input stagnation air temperature in the air turbines
- $\dot{m}$ the warm air mass flow in Kg/sec
- T_4 the exit air temperature at the top of solar chimney
- C_p the specific air heat
- And C_1, C_2 algebraic intermediate expressions.

T_{03} is also the exit air temperature by the solar collector thus can be defined exclusively by the solar collector thermal analysis given the mass flow $\dot{m}$.

An approximate procedure for T_{03} calculation is given by Shlaigh in ref [7]. The approximate equation relating the exit solar collector air temperature T_{03} to its input air temperature T_{02} (valid for circular Solar Collectors) is given by: $ta \cdot G \cdot A_c = \dot{m} \cdot C_p \cdot (T_{03} - T_{02}) + \beta \cdot A_c \cdot (T_{03} - T_{02})$ where:

- β is the approximate thermal power losses coefficient of the Solar Collector (to the ambient and ground) per m^2 of its surface area and ^{0}C of the temperature difference (T_{03}-T_{02}) . An average value for β is ~3.8÷4 W/m^2/^{0}C (for double glazing solar collectors).
- G is the horizontal irradiance on the surface of the solar collector.

The average solar horizontal irradiance G_{av} is given by: G_{av}=annual horizontal irradiation of the place of installation of the SAEPP, (in KWh/m^2) divided by 8760 hours

- ta is the average of the product: {roof transmission coefficient for solar irradiation X soil absorption coefficient for solar irradiation}.An average value of the coefficient ta for a double glazing roof is ~ 0.70 .
- And Ac is the Solar Collector's surface area.

Thus an approximation for the function T_{03} ($\dot{m}$), is given by:

$$T_{03}(\dot{m}) = [\, ta \cdot G / (\beta + \dot{m} \cdot C_p / A_c) \,] - T_{02}$$

Where T_{02} is, approximately, equal to the ambient temperature (T_0 in ^{0}K), plus 0.5 degrees (due mainly to ground thermal storage around the Solar Collector).

The exit temperature T_4 at the top of solar chimney as derived in [] is given by the appropriate root of the polynomial equation:

$$w_1 T_4^{\ 4} + w_2 T_4^{\ 3} + w_3 T_4^{\ 2} + w_4 T_4 + w_5 = 0,$$

where the polynomial coefficients w_1, w_2, w_3, w_4, w_5 are given by the relations:

- $w_1 = C_2^{\ 2}(1-k)$

  $w_2 = C_2 \left(2 - k - n_T C_2 T_4' \right)$

  $w_3 = C_2 C_3 (1-k) + 1 - 2 n_T C_2 T_4'$

  $w_4 = C_3 - n_T T_4' (1 + C_1 C_2)$, $w_5 = -n_T T_4' C_1$,

Where C_1, C_2, C_3 and T_4' are given by:

$C_1 = g \cdot H / C_p$, $T_4' = T_{03} \cdot (1 - C_1 / T_0)$

- $C_2 = a \cdot (R \cdot \dot{m} / (A_{ch} \cdot p_4))^2 / (2 \cdot C_p)$

  $C_3 = T_{o3}(n_T - 1) + C_1$

- where: $A_{ch} = \pi \cdot d^2 / 4$ and $p_4 = p_o (1 - C_1 / T_0)^{3.5}$

and where R, g, C_p are approximately given by: R=287 J/Kg ^{0}C, g=9.81 m/sec^2 and C_p=1005 J/Kg ^{0}C.

- p_0 is the atmospheric pressure at ground level
- η_T is the overall efficiency of the air turbines and generators
- k solar chimney friction loss coefficient and
- α kinetic energy correction coefficient.

Usual values (for an average day) for T_0 and p_0 are: T_0=296 ^{0}K and p_0=101300 Pa .

An average usual value for α is 1.1058.

An average value for η_T is 0.8, for a well-designed air turbine operating around its optimum point of operation.

An average value for k is given by the formula:

k=0.5+0.5·H/3000

Thus using the described procedure the necessary data for the calculation of the average annual electric power output P as function of mass flow $\dot{m}$ are the following:

-The annual solar horizontal irradiation W_y (in KWh/m^2) at the place of installation of the SAEP, by which the average horizontal irradiance G=W_y/8760 is calculated,

- The dimensions of the solar chimney,

(H height in m, d internal diameter in m)

- And the solar collector (greenhouse) surface area Ac in m^2

The approximate annual electricity generation by the SAEP is given by [P(in KW)•8760(hours)] in KWh.

X. References

Periodicals:

[1] J. Schlaich J. e.al 2005, "Design of commercial Solar Updraft Tower Systems-Utilization of Solar Induced Convective Flows for Power Generation" Journal of Solar Energy Engineering Feb. 2005 vol 127, pp. 117-124R.

[2] Gannon A. , Von Backstrom T 2000, "Solar Chimney Cycle Analysis with System loss and solar Collector Performance", Journal of Solar Energy Engineering, August Vol 122/pp.133-137.

[3] Von Backstrom T, Cannon A. 2000, “Compressible Flow Through Solar Power Plant Chimneys”. August vol 122/ pp.138-145.

[4] Gannon A. , Von Backstrom T 2003, “Solar Chimney Turbine Performance”, Journal of Solar Energy Engineering, February Vol 125/pp.101-106.

[5] Bernades M.A. dos S., Vob A., Weinrebe G., 2003 “Thermal and technical analyses of solar chimneys” Solar Energy 75 ELSEVIER, pp. 511-52.

[6] Pretorius J.P., Kroger D.G. 2006,“Solar Chimney Power Plant Performance“, Journal of Solar Energy Engineering, August 2006, Vol 128 pp.302-311

Books:

[7] Schlaich J. 1995, “The Solar Chimney: Electricity from the sun” Axel Mengers Edition, Stutgart

Technical Reports:

[8] USA DOE-Energy International Administration “Annual Energy Outlook 2008” February 2008. Topic, levelized electricity cost.

Papers Presented at Conferences (Unpublished):

[9] Papageorgiou C.D. “Electricity Generation and Climate Change Policies” Keynote speech in IASTED EuroPES conference, June 23-25 2008, Corfu Greece and plenary lecture on WSEAS EPESEE conference, Corfu Greece, October 26-28, 2008

Papers from Conference Proceedings (Published):

[10] Papageorgiou C. 2004 “Solar Turbine Power Stations with Floating Solar Chimneys”. IASTED proceedings of Power and Energy Systems, EuroPES 2004. Rhodes Greece, july 2004 pp,151-158

[11] Papageorgiou C. 2004, “External Wind Effects on Floating Solar Chimney” IASTED Proceedings of Power and Energy Systems, EuroPES 2004, Conference, Rhodes Greece ,July 2004 2004 pp.159-163

[12] Papageorgiou C. 2004, “Efficiency of solar air turbine power stations with floating solar chimneys” IASTED Proceedings of Power and Energy Systems Conference Florida, November 2004, pp. 127-134.

[13] Papageorgiou C. 2005 “Turbines and Generators for Floating Solar Chimney Power Stations”. IASTED Proceedings of Power and Energy Systems, EuroPES conference Benalmadena Spain June 2005.

Dissertations:

[14] Johannes P. Pretorius, "Optimization and Control of a Large-scale Solar Chimney Power Plant" Ph.D. dissertation, Dept. Mechanical Eng., Univ. Stellenbosch 7602 Matieland, South Africa 2007.

Patents:

[15] Christos Papageorgiou "Floating Solar Chimney" E.U. Patent 1618302 April. 29, 2009.

XI. Biographies

Christos D. Papageorgiou Associate Prof. Christos Papageorgiou is a mechanical and electrical Engineer graduated from the National technical University of Athens (NTUA). He is also an Imperial College of London University PhD graduate. He is with the Electrical and computer engineering School of NTUA, in Electro-mechanical systems of thrust and power. His research interests include the solar chimney technology where he invented the ‘’Floating Solar Chimney’’. His research interests also include electromagnetism and quantum mechanics. In his professional career he was appointed to several top managerial positions in public and private sector. His most significant posts were: -C.E.O. of ‘’Olympic Airways’’,- Chairman and President of ‘’Hellenic Railways’’, etc.