2014

Renewable hydrogen production using sailing ships

Platzer, Max F.; Sarigul-Klijn, Nesrin; Young, J.; Ashraf, M.A.; Lai, J.C.S.

ASME

M.F. Platzer, N. Sarigul-Klijn, J. Young, M.A. Ashraf, J.C.S. Lai, "Renewable hydrogen production using sailing ships," Journal of Energy Resource Technology, v.136, (Jun 2014), pp. 021203/1-5.

https://hdl.handle.net/10945/55395

Max F. Platzer
Mechanical and Aerospace Engineering,
Innovative Power Generation Systems (iPGS),
University of California,
Davis, CA 95616
e-mail: maxmillian.platzer@gmail.com

Nesrin Sarigul-Klijn[1]
Mechanical and Aerospace Engineering,
Innovative Power Generation Systems (iPGS),
University of California,
Davis, CA 95616
e-mail: nsarigulklijn@ucdavis.edu

J. Young
The University of New South Wales,
Canberra ACT 2600, Australia
e-mail: J.Young@adfa.edu.au

M. A. Ashraf
The University of New South Wales,
Canberra ACT 2600, Australia
e-mail: M.ashraf@adfa.edu.au

J. C. S. Lai
The University of New South Wales,
Canberra ACT 2600, Australia
e-mail: j.tai@adfa.edu.au

Renewable Hydrogen Production Using Sailing Ships

Vast ocean areas of planet Earth are exposed year-round to strong wind currents. We suggest that this untapped ocean wind power be exploited by the use of sailing ships. The availability of constantly updated meteorological information makes it possible to operate the ships in ocean areas with optimum wind power so that the propulsive ship power can be converted into electric power by means of ship-mounted hydro-power generators. Their electric power output then is fed into ship-mounted electrolyzers to convert sea water into hydrogen and oxygen. In this paper, we estimate the ship size, sail area, and generator size to produce a 1.5 MW electrical power output. We describe a new oscillating-wing hydro-power generator and present results of model tests obtained in a towing tank. Navier-Stokes computations are presented to provide an estimate of the power extraction efficiency and drag coefficient of such a generator which depends on a range of parameters such as foil maximum pitch angles, plunge amplitude, phase between pitch and plunge and load. Also, we present a discussion of the feasibility of sea water electrolysis and of the reconversion of hydrogen and oxygen into electricity by means of shore-based hydrogen-oxygen power plants. [DOI: 10.1115/1.4026200]

1 Introduction

Any discussion of the feasibility of transitioning to renewably generated energy has to start with an examination of the availability and accessibility of the various known energy sources. Authors of recent books on renewable energy and on the climate crisis [1–7] have emphasized the urgent need for finding additional energy sources and power production methods that emit very little carbon dioxide.

In our two previous papers [8,9], we tried to draw attention to the fact that at the present time only a small part of the total global wind energy is being exploited. Most of the wind power can be found over the oceans which cover 70% of the planet's surface area. This shows that there is plenty of wind power to satisfy the global needs. In our papers, we proposed to make the ocean surface wind power accessible by the use of sailing ships which are equipped with hydropower generators to generate on-board electricity for the conversion of sea water into hydrogen and oxygen which then are compressed and delivered to shore-based hydrogen-oxygen power plants for reconversion into electricity and potable water. Discussions of the importance of renewably produced hydrogen for an emission-free economy can be found in Refs. [10–14].

It is the objective of our paper to provide additional details and results of our continuing studies of this scenario. In the first part, we describe the size, design and operating characteristics of a sailing ship for a 1.5 MW power output. In the second part, we present results of our most recent experiments and analyses of the oscillating-wing hydropower generator we proposed in our previous two papers.

2 Sailing Ship Characteristics

For a preliminary assessment of the feasibility of sailing ship-based power generation, we regard it as advisable to base the analysis as much as possible on known ship characteristics. Therefore we selected the David Taylor Model Basin Wave Cancellation Multihull (WCM) trimaran as a suitable baseline design. The principal dimensions of this trimaran are: Center Main hull length: 119 m, center main hull draft: 9 m, outrigger hull length: 58 m, outrigger hull draft: 4.2 m, outrigger hull spacing: 32.3 m, total wet surface area: 3891 m^2.

This WCM trimaran and a much smaller trimaran built at the Dalhousie University in Canada were investigated in detail in Hongxuan Peng's PhD thesis [15] where it is shown that the wave resistance coefficient is typically around 0.001 and the total resistance coefficient for the Dalhousie trimaran is approximately 0.004.

Therefore, we postulate a trimaran similar to the WCM trimaran with a wetted area of 5000 m^2 and a resistance coefficient of 0.004. The propulsive force which can be produced by a wind sail under the most favorable wind angle conditions can be obtained from a typical airfoil polar diagram, as discussed, for example, by Smulders [16]. The true wind vector and the ship velocity vector need to be added to give the apparent wind vector. The most favorable conditions occur when the ship is "beam reaching," i.e., when the apparent wind vector is approximately perpendicular to the path of the ship. The total aerodynamic force generated by the sail then is approximately in the direction of the ship, providing a net thrust force. For our analysis, we assume a thrust coefficient of 2.0 as being a conservative value. Furthermore, we analyze the ship performance for three different values of the apparent speed (7.5 m/s, 10 m/s, and 12.5 m/s) as realistic wind conditions. Actual wind speed values will of course vary with the ship speed and can easily be reconstructed if needed.

Addition of a hydro-turbine or of an oscillating-wing power generator produces a significant additional drag. In this paper we limit the discussion to the oscillating-wing generator. We show in

---

[1] Corresponding author.

Contributed by the Advanced Energy Systems Division of ASME for publication in the JOURNAL OF ENERGY RESOURCES TECHNOLOGY. Manuscript received September 1, 2012; final manuscript received December 4, 2013; published online February 20, 2014. Assoc. Editor: Laura Schaefer.

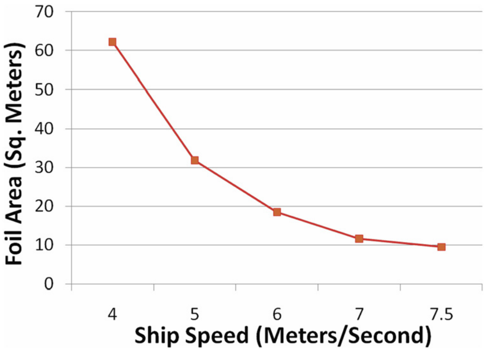

Fig. 1 Generator foil area versus ship speed

the second part of our paper that a drag coefficient of 2.0 is a reasonable estimate. Furthermore, we show that a reasonable estimate of the power output of the oscillating-wing generator is to assume a power coefficient, c_p of 0.8.

Using these assumptions, we can obtain the foil area of the oscillating-wing power generator from the equation for the power output

$$P = c_p\left(\frac{1}{2}\rho U^3\right)S \quad (1)$$

where c_p is the power coefficient, ρ *is* the water density, U is the ship speed, and S is the foil area.

Figure 1 shows the decrease of the generator foil area needed as the ship speed is increased from 4 m/s to 7.5 m/s to produce a power output of 1593 kW. As one would expect, the generator size decreases significantly with increasing water speed. For the same range of ship speeds, the ship drag is computed from the equation

$$D_S = 0.004\left(\frac{1}{2}\rho U^2\right)A_w \quad (2)$$

where D_S is the ship drag and A_w the wetted ship area (equal to 5000 m^2). Similarly, the generator drag is obtained from the equation

$$D_G = 2\left(\frac{1}{2}\rho U^2\right)S \quad (3)$$

The sum of the two drag values must be balanced by the sail thrust T given by

$$T = 2\left(\frac{1}{2}\rho_A U_A^2\right)S_S \quad (4)$$

where ρ_A is the air density, U_A is the apparent wind speed, and S_S is the sail area.

Figure 2 shows the sail area required to produce a power output of 1593 kW as a function of ship speed for apparent wind speeds of 7.5 m/s, 10 m/s, and 12.5 m/s. Again, as one would expect, the required sail area decreases with increasing wind speed. It is also seen that the required sail area decreases slightly as the ship speed is increased from 4 m/s to 6 m/s before increasing with additional ship speed. This is due to the fact that a significantly larger generator foil area is required at low speeds thus causing more total drag in spite of the lower ship drag.

Further sail area reductions can be achieved for wind speeds higher than 12.5 m/s or if higher sail lift coefficients and smaller wetted areas are assumed. Hydrofoil boats are likely to offer considerable performance gains. For example, Hoppe [17] demonstrated resistance improvements of over 40% against catamarans. Another innovative boat was developed by Marine Advanced Research Inc [18]. It has twin hulls, like a catamaran, connected to each other and the crew cabin by four metal legs. The legs ride on titanium springs—like shock absorbers—that allow the boat to adapt to the waves and enable a much smoother ride than other boat designs.

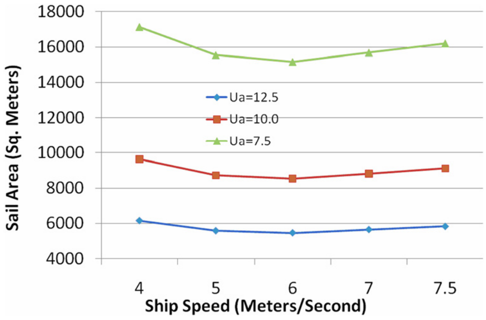

Fig. 2 Sail area versus ship speed

3 Electric Power Generation

It is apparent from the above discussion that for the generation of electricity from typical wind speeds, say 7.5 to 12.5 m/s, the required capture area for a significant power output, say 1 to 2 MW, is quite large. For this reason, the blade length of the General Electric 1.5 MW turbine is 40 m. For the same reason, the wind capture and therefore the sail area of a sailing ship has to be equally large or even larger than for a land-based wind turbine. Our proposal to use sailing ships is based on the consideration to open up the vast ocean areas for power generation.

A further advantage to be gained from the use of sailing ships is the small size of the power generator due to the availability of relatively high water speeds, say 4 to 7.5 m/s. Hence, conventional hydro-turbines could be used to convert the kinetic energy of the water into electricity.

In this paper, we would like to draw attention to a second type of power generator which might have advantages over hydro-turbines. It is based on the reciprocating rather than the rotary motion principle.

4 Oscillating-Wing Power Generation

It is well known to aeronautical engineers that oscillating wings may extract power from an air stream. The bending and torsion flexure of airplane wings exposed to an air flow may extract sufficient energy to result in structural damage or even catastrophic failure if there is a 90 deg phase angle between the bending and torsion oscillations. Fortunately, this phenomenon can also be used to extract energy from a wind or water stream and convert it into electric power.

In 1981, McKinney and DeLaurier [19] at the University of Toronto appear to have been the first ones who built an oscillating-wing windmill for the purpose of exploiting this flutter phenomenon for power generation. It consisted of a horizontally mounted wing whose plunging motion was transformed into a rotary shaft motion. The operating principle can be readily understood by looking at the single-foil generator, shown in Fig. 3, which we demonstrated ten years ago [20]. It shows a foil which can be driven into a coupled pitch and plunge motion by a mechanism consisting of a swing arm, a push-rod, a phasing gear to enforce a phase angle between the pitch and plunge motions of about 90 deg, a bell-crank and push-rods. It operated quite satisfactorily.

In the late 1990s the British company Engineering Business Limited [21] started the development of a 150 kW oscillating-foil hydropower generator to produce power from a 4-knot tidal stream. It had a single hydrofoil with a chord length of 3 m and a span of 15.5 m. The pitch/plunge motion of the hydrofoil caused an arm to pitch up and down which, in turn, was connected to

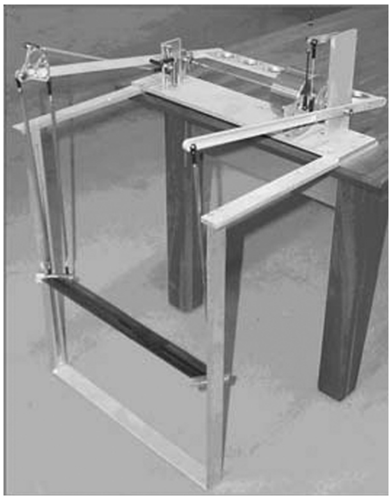

Fig. 3 Mechanically controlled generator

hydraulic cylinders whose high-pressure oil drove a hydraulic motor connected to an electric generator. Tests in Yell Sound in Shetland showed that the power generator was capable of producing 90 kW in a 1.5 m/s flow, but further development was stopped in 2004 due to lack of additional funding by the British Department of Trade and Industry. Recently another British company Pulse Generation Limited[2] demonstrated, once more, the feasibility and practicality of using oscillating hydrofoils for the generation of 100 kW from tidal flows in the river Humber. Also, at Laval University in Canada computational and experimental investigations of a 2 kW prototype of an oscillating-wing hydropower generator showed that power extraction efficiencies of 40% are possible [22,23].

During the past few years, we have developed a new design of an oscillating-foil power generator [7,8], because the large number of mechanical parts needed for pitch-plunge phase angle control used in the power generators shown in Fig. 3 is an unwelcome feature. During the translatory up and down motion of the foil, the pitch angle had to be controlled with the swing arms seen in Fig. 3. This concern led us to the development of an oscillating-foil generator which uses a simpler and more effective system to achieve the proper phasing between the pitch and plunge motions of the foil.

The major new innovation introduced into our new power generator consists of the realization that the pitch angle and the phasing can be controlled by purely hydrodynamic means, thus eliminating the many parts needed for the mechanical control system. As is well known, a foil is statically unstable if it is free to pitch about an axis which is located sufficiently far downstream from the foil's aerodynamic center. Hence locating the pitch axis sufficiently far downstream will assure that the foil is pitched to an increasing pitch angle until it is stopped by a mechanical restraint.

The new generator is shown in Figs. 4 and 5. A small aluminum block runs on two rails and the foil is attached to the block by means of a shaft, permitting to set foil pitch angles between 0 and 70 deg. The pitch axis of the foil is set at 60% chord. The foil is a 2 mm thick 84 × 192 mm aluminum flat plate. Because of the 60% chord position of the pitch axis the foil is statically unstable causing it to pitch either to the left or right when exposed to the water flow. In the tests described further below the pitch amplitude was limited to 60 deg by means of a suitably positioned mechanical constraint. Also shown in Figs. 4 and 5 are two small rods. It is the function of these two control rods to reverse the foil's plunge motion. This is accomplished by placing the control rods upstream of the foil's midchord position at 44% chord where the foil is sliding along the two rails in response to the lift force generated by the foil which is deflected to a large pitch angle. Assume the flow in Fig. 4 to approach from the upper right corner. The foil then is driven from right to left and approaches the left control rod visible in Fig. 5. As soon as the foil touches the control rod, a hydrodynamic pitch moment is generated which induces the foil to pivot about the control rod. As a consequence, the foil is deflected to a large pitch angle of opposite sign to the one before it hit the control rod. In response to this new pitch angle, the foil starts to slide on the two rails to the right until it hits the control rod on the right side and the foil is again pivoted around it. As a consequence, a square-wave type foil oscillation is being generated. This is advantageous because it transfers more energy per cycle than a purely sinusoidal oscillation. The plunge amplitude can be varied by placing the two control rods at various positions in the row of holes shown in Figs. 4 and 5. The dimensions of the aluminum block holding the two guide rails are 381 × 152 mm.

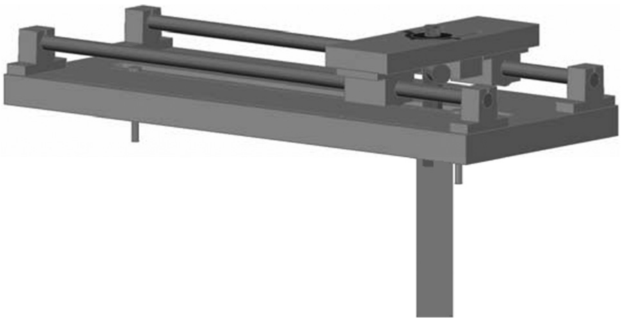

Fig. 4 New generator

The tests described in this paper comprised the investigation of the effect of plunge amplitude and flow speed on the operation of the power generator. The power generator was mounted on a carriage so that it could be towed in the towing tank of the Department of Mechanical & Aerospace Engineering of the Naval Postgraduate School in Monterey, California. The foil was submerged in the water to a depth of 115 mm so that the total wetted foil area was 84 × 115 mm. The towing distance was 9 m. The generator performance was explored for towing speeds between 0.6 and 1.2 m/s, measured with a MiniWater6 Micro anemometer. The drag force on the generator was measured with a Honeywell AL111BN 30b Model 41 load cell making it possible to compare the drag generated by the oscillating foil with the drag forces generated by the blade held at a steady 60 and 90 deg deflection angle and zero degree angle of attack. This comparison is shown in Fig. 6.

It is seen that the steady foil deflected at 60 deg generates a slightly larger drag than the oscillating foil, while the steady foil deflected at 90 deg generates a much larger drag and the foil held at zero angle of attack generates a much smaller drag, as one would expect. Also, as expected, the drag increases significantly

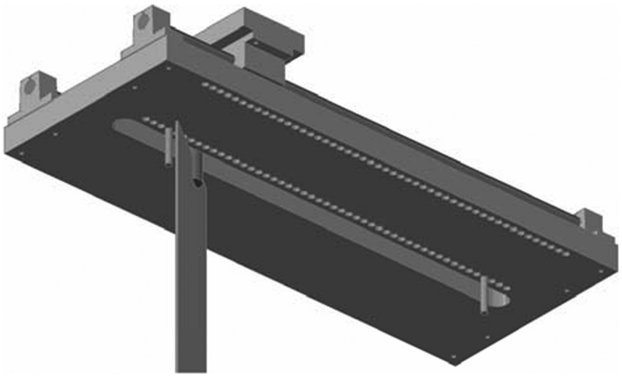

Fig. 5 New generator

---

[2] http://www.pulsegeneration.co.uk

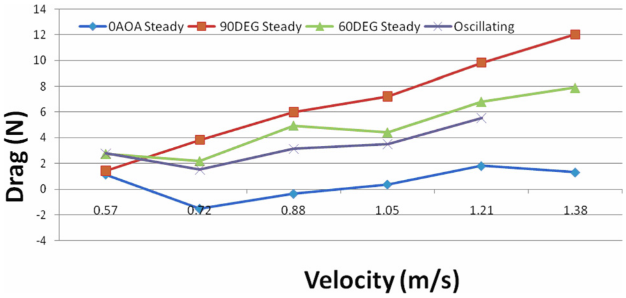

Fig. 6 Generator drag versus water speed

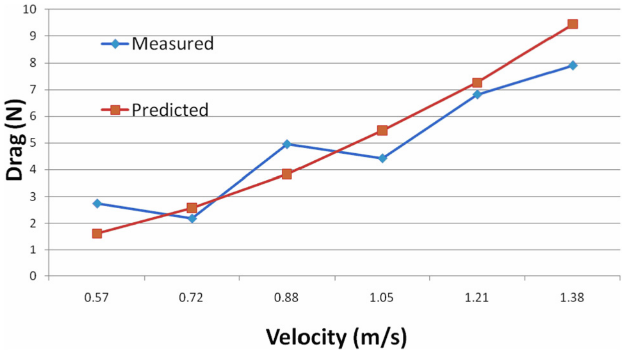

Fig. 7 Estimated and measured steady drag

with flow speed. In Fig. 7, the measured drag of the steady foil deflected at 60 deg is compared with the estimated drag based on a drag coefficient of 1.2 and a foil area based on the product of the wetted foil area and the sine of the 60 deg deflection angle. It is seen that the agreement is quite good.

5 Computational Analysis

In parallel to this experimental program, we developed computational simulations to predict the flow through oscillating-foil power generators. To this end, both potential flow and viscous flow codes were developed using panel methods and viscous flow (Navier-Stokes) codes. Some of our previous computational predictions are documented in Refs. [24–26]. Here, we show our most recent computations applied to the new oscillating-foil power generator described in the previous paragraphs.

A 2D Navier Stokes model was used to simulate the oscillating foil generator in the commercial CFD package Ansys 12.1. As described in [27], grid-independence and time-step independence tests were conducted. As a result, a grid with 186,000 cells and 400 cells on the foil surface and a time step of $\Delta t = 1.25 \times 10^{-3}$ s were chosen for all the simulations here. The first cell height from the foil surface was $\Delta = 1.0 \times 10^{-4}$ chords, resulting in a cell Reynolds number $\mathrm{Re}_c = \omega\Delta 2/\nu = 0.2$–$1.2$ on the foil surface at all times. This mesh choice also provided excellent agreement with the time history of aerodynamic forces for the optimum prescribed-motion case of Kinsey and Dumas [22] for a NACA0015 foil, as shown in Ref. [27].

The model is not a precise emulation of the experimental mechanism, in that the motion of the foil is controlled via a geneva wheel linked to a flywheel, rather than via the two control rods. However, it closely replicates the nonsinusoidal motion experienced by the experimental foil and is similarly fully flow-driven. Power extraction is modeled via a damper attached to the flywheel. This effective load on the system is nondimensionalized by the idealized fluid damping on a rotating flat plate. Similarly the inertia of the flywheel and foil combination is nondimensionalized by considering the ratio of kinetic energy in the flywheel and moving foil, compared to the kinetic energy of the ideal fluid added mass and inertia of a plunging and pitching plate.

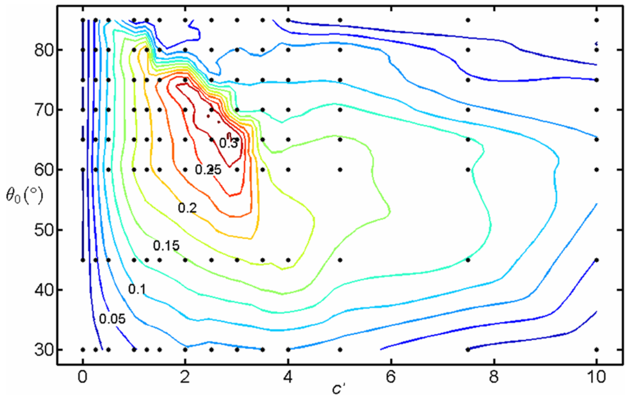

Fig. 8 Contours of power extraction efficiency versus foil pitch angle and nondimensional load

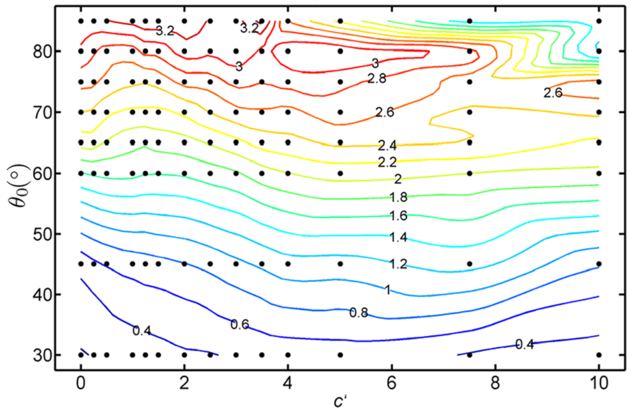

Fig. 9 Contours of drag coefficient versus foil pitch angle and nondimensional load

Figures 8 and 9 show the predicted power extraction efficiency and drag coefficient, for a range of foil maximum pitch angles and non-dimensional load. Black dots indicate the runs conducted. All runs shown were conducted for a NACA0012 foil at a Reynolds number $\mathrm{Re} = 1100$, with a plunge amplitude of 1.0 chord, foil pivot point at midchord, and nondimensional inertia $I' = 5.67$. Also the motion was nonsinusoidal, with a pitch angle waveform 40% of the way between a full square wave and a full sinusoid (shown to give best performance [26]), and pitch leading plunge by 90 deg.

The efficiency contours show a broad peak at about 30% efficiency, commensurate with other flapping-foil analyses, but also indicate the sensitivity of the performance to load on the system. These results do not necessarily represent the best performance that could be achieved, with further optimization against parameters such as plunge amplitude, phase between pitch and plunge and location of the pivot point. The drag coefficient in this efficiency peak region is approximately 2.2, and noting that the simulation was conducted in overly viscous conditions ($\mathrm{Re} = 1100$), the value of 2.0 used in the preceding analysis is reasonable.

6 Seawater Electrolysis

An additional key technology needed for the exploitation of ocean surface winds is the feasibility of storing the electric energy generated on the sailing ship. Sea water electrolysis for on-board production of hydrogen and oxygen is likely to offer the best solution. Koji Hashimoto and associates at the Institute for Materials Research of Tohoku Institute of Technology in Sendai, Japan, have demonstrated an energy-saving technique to split sea water into hydrogen and oxygen [28]. The electrolytic cell, similar to fresh water electrolytic cells, consists of an anode, a cathode, and a membrane to separate these electrodes. The small amounts of calcium and magnesium ions contained in sea water are removed before electrolysis in order to prevent the formation of calcium and magnesium hydroxide on the cathode and on the membrane surface of the cathode side. This removal is accomplished by passing sea water through a chelate resin column. Furthermore, instead of simultaneous parallel feeding of sodium chloride solution to both anode and cathode compartments, neutral sodium chloride solution is fed first to the anode compartment and the low pH solution from the outlet of the anode compartment is then fed to the cathode compartment. The details are described in Ref. [28]. According to Hashimoto [29], 1 MWh electricity produces 119.4 m^3/h of hydrogen and 59.7 m^3/h of oxygen, consuming 96 kg/h of seawater. Typical commercial freshwater electrolyzers require 70 to 53 kWh to produce a kg of hydrogen. Since 11.2 m^3 of hydrogen equals 1 kg of hydrogen, for seawater electrolysis 93.8 kWh electricity are required to produce 1 kg of hydrogen. Hence seawater electrolysis, at the present state of development, requires significantly more energy than freshwater electrolysis.

7 Hydrogen-Oxygen Power Plant

A further additional key technology for the exploitation of ocean surface winds is the feasibility of efficiently reconverting the stored hydrogen and oxygen into electricity. Jericha et al [30] describe a hybrid power plant which incorporates solid oxide fuel cells into an innovative power cycle with steam as working fluid. The power plant is based on a previous proposal by Jericha [31] to use a high-temperature and a low-temperature cycle.

8 Conclusions

Seventy percent of the planet's surface is covered by oceans where most of the wind power can be found. Yet, recent reviews of various renewable energy technologies [1–6] limit the discussion of wind power generation to land and off-shore based power plants and only one proposal has recently been made to use parawing-driven large ships for the exploitation of the wind power over the oceans at an altitude of 1480 m [32]. In two previous papers [7,8], we suggested the use of sailing ships for the exploitation of the vast wind power available close to the ocean surface. In this paper we provide a more detailed analysis of the sailing ship size and operating conditions to generate 1.5 MW electric power and we describe a new oscillating-wing hydropower generator. Results of small-scale tests of this power generator together with Navier-Stokes computations of its flow and performance characteristics confirm its potential as a competitor with conventional hydro-turbines. Also, the currently available information about the feasibility of sea water electrolysis into hydrogen and oxygen and their reconversion into electric power and potable water in shore-based hydrogen-oxygen power plants is summarized. It indicates that the major technologies are available to implement the concept of sailingship-based renewable energy and potable water generation. Hence a fleet of large sailing ships with electric power outputs of 1 to 5 MW per ship may be able to make a significant contribution to the solution of the world's growing energy and potable water crisis.

Acknowledgment

We are grateful to Professor K. Millsaps for permission to use the facilities of the Hydrodynamics Laboratory of the Naval Postgraduate School, to John Mobley and Tom Smith for their machine shop support and Vinay Mistry for assistance in model testing and data reduction.

References

[1] Al Gore, 2009, "Our Choice," Melcher Media.
[2] Jay, I., and Bracken, H., 2008, *Apollo's Fire, Igniting America's Clean Energy Economy*, Island Press, Washington, DC.
[3] James, H., 2009, *Storms of my Grandchildren*, Bloomsbury, New York.
[4] Peter, D. W., 2010, *The Flooded Earth—Our Future in a World without Ice Caps*, Basic Books, New York.
[5] Vaclav, S., 2008, *Energy in Nature and Society*, The MIT Press, Cambridge, MA.
[6] Lester, R. B., 2011, *World on the Edge, How to Prevent Environmental and Economic Collapse*, W. W. Norton & Co., New York.
[7] Max, F. P., and Nesrin, S.-K., 2012, *Aerohydronautical Power Engineering: Is It the Key to Abundant Renewable Energy and Potable Water?*, University Publishers, San Diego, CA.
[8] Max, F. P., and Nesrin, S.-K., 2009, "A Novel Approach to Extract Power from Free-Flowing Water and High-Altitude Jet Streams," ASME Energy Sustainability Conference, San Francisco, CA, 19-23 June, Paper No. ES 2009-90146.
[9] Max, F. P., and Nesrin, S.-K., 2010, "A New Oscillating-Foil Power Generator for Sailingship-Based Renewable Energy Generation," ASME Energy Sustainability Conference, Phoenix, AZ, 17–22 May.
[10] Shiva Prasad, B. G., 2010, "Energy Efficiency, Sources and Sustainability," ASME J. Energy Resour. Technol., **132**(2), p. 020301.
[11] Fronk, B. M., Neal, R., and Garimella, S., 2010, "Evolution of the Transition to a World Driven by Renewable Energy," ASME J. Energy Resour. Technol., **132**(2), p. 021009.
[12] Vellini, M., and Tonziello, J., 2011, "Hydrogen Use in an Urban District: Energy and Environmental Comparisons," ASME J. Energy Resour. Technol., **132**(4), p. 042601.
[13] Shahid, M., Bidin, N., Mat, Y., and Inayat ullah, M., 2012, "Production and Enhancement of Hydrogen from Water: A Review," ASME J. Energy Resour. Technol., **134**(3), p. 034002.
[14] Ajanovic, A., Jungmeier, G., Beermann, M., and Haas, R., 2013, "Driving on Renewables—On the Prospects of Alternative Fuels up to 2050 from an Energetic Point-of-View in European Union Countries," ASME J. Energy Resour. Technol., **135**(3), p. 031201.
[15] Hongxuang, P., 2001, "Numerical Computation of Multi-Hull Ship Resistance and Motion," Ph.D. thesis, Dalhousie University, Nova Scotia, Canada.
[16] Freej, S., 1985, "Exposition of Calculation Methods to Analyze Wind Propulsion on Cargo Ships," J. Wind. Eng. Ind. Aerodyn., **19**(1–3), pp. 187–203.
[17] Hoppe, K. G., 1999, "Hydrofoil Catamaran Development in South Africa," HIPER'99 International Conference at Zevenwacht, South Africa, 17–19 March.
[18] www.wam-v.com/
[19] McKinney, W., and DeLaurier, J., 1981, "The Wingmill: An Oscillating-Wing Windmill," J. Energy, **5**(2), pp. 109–115.
[20] Jones, K. D., Davids, S. T., and Platzer, M. F., 1999, "Oscillating-Wing Power Generation," 3rd ASME/JSME Joint Fluids Engineering Conference, San Francisco, CA.
[21] The Engineering Business Limited, Stingray Tidal Energy Device-Phase 3, 2005, Tech. Report No. T/06/00230/00/00.
[22] Kinsey, T., and Dumas, G., 2008, "Parametric Study of an Oscillating Airfoil in a Power-Extraction Regime," AIAA J., **46**(6), pp. 1318–1380.
[23] Kinsey, T., and Dumas, G., 2010, "Testing and Analysis of an Oscillating Hydrofoils Turbine Concept," ASME FEDSM-ICNMM2010-30869, Aug. 1–5.
[24] Platzer, M. F., Ashraf, M. A., Young, J., and Lai, J. C. S., 2010, "Extracting Power in Jet Streams: Pushing the Performance of Flapping-Wing Technology," 27th International Congress of the Aeronautical Sciences, Nice, France, 19–24 Sept.
[25] Young, J., Ashraf, M., Lai, J. C. S., and Platzer, M. F., 2010, "Numerical simulation of Flow-Driven Flapping-Wing Turbines for Wind and Water Power Generation," Proceedings of 17th Australasian Fluid Mechanics Conference, Auckland, New Zealand, 5–9 Dec.
[26] Ashraf, M. A., Young, J., Lai, J. C. S., and Platzer, M. F., 2011, "Numerical Analysis of an Oscillating-Wing Wind and Hydropower Generator," AIAA J., **49**(7), pp. 1374–1386.
[27] Young, J., Ashraf, M. A., Lai, J. C. S., and Platzer, M. F., 2013, "Numerical Simulation of Fully Passive Flapping Foil Power Generation," AIAA J. (on-line pre-print).
[28] Kato, Z., Izumiya, K., Kumnagai, N., and Hashimoto, K., 2009, "Energy-Saving Seawater Electrolysis for Hydrogen Production," J. Solid State Electrochem., **13**(2), pp. 219–224.
[29] Koji, H., 2010, Tohoku Institute of Technology, Japan, private email communication.
[30] Jericha, H., Hacker, V., Sanz, W., and Zotter, G., 2010, "Thermal Steam Power Plant Fired by Hydrogen and Oxygen in Stoichiometric Ratio, Using Fuel Cells and Gas Turbine Cycle Components," June 14–18, Paper No. ASME GT2010-22282.
[31] Jericha, H., 1985, "Efficient Steam Cycles With Internal Combustion of Hydrogen and Stoichiometric Oxygen," CIMAC Paper.
[32] Kim, J., and Park, C., 2010, "Wind Power Generation With a Parawing on Ships, a Proposal," J. Energy, **35**, pp. 1425–1432.