FROM WAVE TO JET AND FROM JET TO HYDROGEN

Rafael Sánchez-Dirzo[1], Rosa de Gpe. González-Huerta[2], Edgar G. Mendoza-Baldwin[3] y Rodolfo Silva-Casarín[4]

[1]Facultad de Estudios Superiores Zaragoza, *Campus* II, UNAM. Batalla del 5 de mayo s/n esq. Fuerte de Loreto, Col. Ejército de Oriente, C.P. 09230, Deleg. Iztapalapa, México, D.F. [2]ESIQIE-IPN, Unidad Zacatenco, México, D.F. [3,4]Instituto de Ingeniería, UNAM. Ciudad Universitaria, México, D.F
E-mail: [1]rafaelsanchezdirzo@yahoo.com.mx, [2]rosgonzalez_h@yahoo.com.mx,
[3]EMendozaB@ii.unam.mx, [4]RSilvaC@ii.unam.mx

ABSTRACT

Device marine proposal, *Blowjet*, with close aerofoil profile to take advantage of surge energy is presented. Wave train complexity can be simplified using the well-known hydrodynamics model of the water spurt by means of the profile of the called wind instrument, tuba. The main goal of this work is to reproduces the famous coastal phenomenon known like "*bufadora*" to obtain a water-jet. This makes turbo generator work, which is an ocean energy systems innovation. The *Blowjet* can be integrated to electrolysis-fuel cell system, in order to accumulate wave energy and became to hydrogen. The power plant prototype is in the integration process in the laboratory, each one of the devices is being tested.

Electrolysis is the simplest process for hydrogen production, it has been known for more than two hundred years, but currently, scale industrial electricity generation from photovoltaic systems, wind or ocean energy, has not been solved. While developments in wind and solar systems energy generation have been well documented in recent years, investigations in sea systems energy generation are just beginning. Mexico has more than twelve thousand kilometres of coastline and more than thousand islands. We should look towards the sea and research for developing sustainable energy sources.

1. Introduction

At same time as development of the technologies that transform the solar energy [1], wind [2] and biomass [3] to convert particular work in electricity, others technologies are been developed to transform the surge, sea currents, tides, concentration gradients and thermal gradients energies to finds blunting with more than thousand patented devices [4] and every year new designs and innovations are added to diminish the presence of the hydrocarbons in its fuel paper [5].

From all these concepts, models and prototypes, around twenty are highlight by their ingenuity, realised investments and supports as much deprived as public [6][7][8][9][10][11][12]. Although the most of the technologies concentrates the transformation of the waves and currents of tides, the techniques that make use of the thermal gradients [13][14], salts gradients [15], ocean currents [16] and the concepts where all the renewable energies are hybrid and are presented in a single Power Station of Power integrating zones of storage, they begin to draw attention by their great potential [17][18][19][20][21][22][23]. Then, the dynamics of the renewable energies begins to take own form without historical precedents [24].

The main reason of the forces of the surge investigation, its hydrodynamics and the impact on the coast has been the coastal protection and they support the conception, design, construction, tests and operation of power devices [25][26][27][28][29][30][31]. Particularly, energy transformations in the waves breaking zone, their ascent and reduction by the coasts have a wide range of theoretical and experimental studies that allow to be taken into account for diverse designs of ocean/coastal energy converters on the coastline.

The oscillations of the waves on the coastline is transformed in to a movement toward the front by means of know devices and in phase of commercialization known like Oscillating Water Column that even begins to simulate [32].The movement of ascent of the surge on the coast has been proven by means of inclined planes which bring the amplification effect that cause that the water lifts several meters on the sea mean water level where it is stored in a coastal dam to again return to the ocean generating electricity. This set of walls that conform a channel open in narrowing and which they amplify the marine waves is known like TAPCHAN (TAPeredCHANnel).

The TAPCHAN emphasizes like the transformation device energetics of the surge on the coastal line, simpler and elegant [33][34]. An example of this kind of device has been proven in Norway [35][36][37][38], see figure 1.

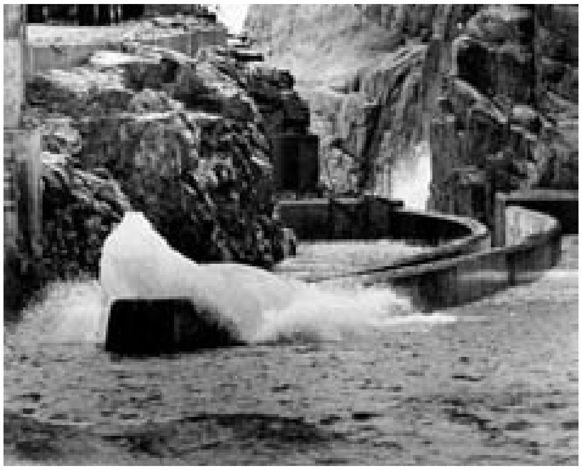

Figura 1. TAPCHAN

The *Blowjet* takes some ideas from the tapchan and aims to reproduce the hydraulic behaviour of the well-known, naturally occurring blowhole or "sea cavern" structure. Blowholes occur all over the world and are known locally by different names; the most famous example on the Mexican coast is that located on the North Pacific, in Ensenada, Baja California, and called the "Bufadora", figure 2 (YouTube), which is an onomatopoeic term and several examples could be found also in Australia and Hawaii. Although it has been described very briefly by the specialized bibliography [39][40], it suggests another form to operate the surge energy.

Figure 2. Bufadora, Mexico

This natural coastal feature sees wave energy compressed in a narrowing space and blasting out of a chimney in a spectacular form. The complex internal morphology of blowholes has been poorly studied, what we do know is that this natural formation always presents a catchment entrance, a compression cavern and an expelling hole. The different sizes, slopes and arrangement of these three components determine the force and air-water mixture of the expelled jet. In terms of designing a wave energy converter based upon this hydraulic operation it is desirable to reduce wave reflection, minimize resonance inside the device and avoid an excessive air-water mixture.

Based on observation of the natural blowholes energy transformation process, this paper presents a device which maximize wave energy conversion in a similar way to that of a "blow hole" with a close hydrodynamic profile where waves funnel up and out and the water is compressed as tube becomes smaller and smaller causing the pressure to increase forcing a stream of water to shoot up to ten meters into the air. The complex nature of the wave train can be simplified as a mere flow of water as it passes through a musical instrument, the tuba. In terms of energy conversion, the blowhole turns relatively small waves into very strong water jets. The great advantage of this structure is that only kinetic energy is amplified and it can be easily directed to a turbine. Also, once the water has been used to move the turbine, it can be easily returned to the sea and no further storage is needed.

Looking at the transformation of the wave energy, from kinetic to potential, the blow jet is a variation of the recent TAPCHAN, consisting of an open channel which, on narrowing, converts wave energy into potential energy. This is then transformed into kinetic energy in a closed TAPCHAN and the water is expelled with great force. From a theoretical model of the energy control balance, the aim of this study is to presents design criteria of the *Blowjet*.

2. Experimental Section

All the experimental work was held at the wave flume of the National University of Mexico. This is a 37 m long, 1.2m high and 0.8 m wide flume with a piston type wave maker. The flume is made of glass in one side and stainless steel in the other and the bottom (Figure 4). The flume is equipped with an active wave absorber attached to the paddle and a passive one at the other end. The experimental set up for the *Blowjet* consisted in three wave gauges at the front of the device for registering the incident and reflected waves and one more gauge behind the device to get the transmitted ones. The water velocities at the entrance of the device and at the jet were measured with micro ADV's and PIV respectively. More than 300 tests were carried out with the *Blowjet* device; regular wave trains with different height (8 to 20 cm) and period (0.8 to 2.0 s) were generated. Four device's axis angle from the still water level were tested (0, 10, 20 and 30 degrees) for three relative submergences (1/3, 1/2 and 2/3 of the Blow-Jet entrance area). Some conditions were eliminated from the analysis because waves were breaking before reaching the device.

Figure 3 shows all the elements of the *Blowjet* in the lab that is shown in Figure 3. Profile, is initially set the inlet and outlet diameter of the device. Then to each fraction of submersion of the device are made to change its inclination angle, height and the wave period to stay registered mainly, the speed of the jet.

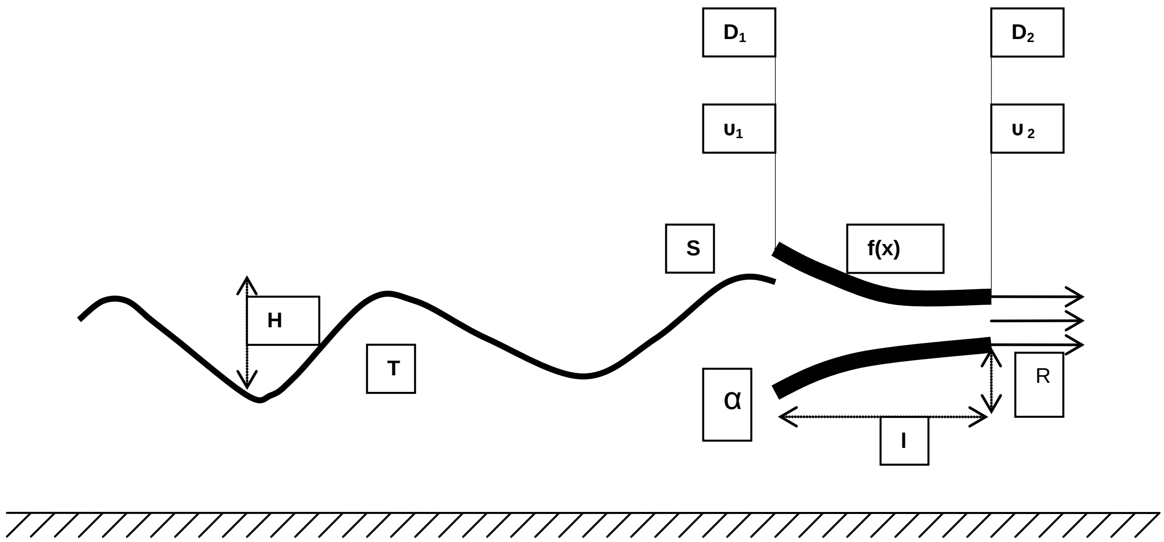

Figure 3. Experimental Diagram

Where:
T = Period [s], H = Height of the wave [m], f (x) = Hydrodynamic Profile of *Blowjet*, **l** = Length of *Blowjet* [m], R = Radio of *Blowjet*, D_1 = Inlet diameter [mm], υ_1 = Speed to the entrance [m/s], υ_2 = Speed when coming out [m/s] D_2 = Outlet diameter [mm], α = Pending of the device, S=Submersion level

The tests were made with the magnitudes:

f(x) = $1.37178\ x^{3/4}$
l = 630 mm
R = 172 mm
D_2 = 21 mm
D_1 = 366 mm
S = 1/3, 1/2, 2/3
α **[°]** = 0, 10, 20, 30
H [m] = 0.08, 0.12, 0.16, 0.2
T [s] = 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, 2.0

The setup of the experiments is illustrated in Figure 4.

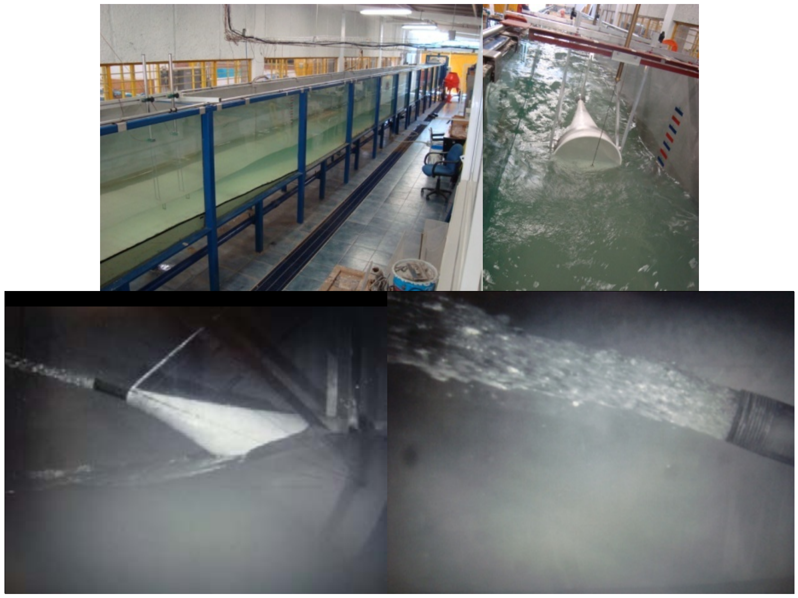

Figure 4. ***Blowjet***

The *Blowjet* has been positively received with interest in various congresses where it has been presented, it is in innovation and improvement process by their authors [41][42][43][44].

3. Results and discussion

The normalized maximum and mean velocity in the outlet of the *Blowjet* are showed figure 5 and Figure 6, respectively, where S_1 is the proportion of the inlet diameter flooded with water.

Blowjet reduces the complexity of the sea wave transformation to the elemental hydrodynamics of a water-jet allowing calculate theoretically the power of the jet as $\beta \sim v^3$. The results show a wide range of jet velocities that range its power from 5 to 19 watts. The experimental results obtained with small waves, between 8 and 20 centimetres in heights and periods between 0.8 and 2 seconds, shows that they are able to carry so much energy per unit of time.

Actually, a research group from IPN and UNAM are in the process of designing and building a turbo-generation system able of produce energy from 1.7 to 2.5 volts and amperage between 10-300 mA, with pulses that match the period of the water waves. These features will undoubtedly be able to integrate for the first time a device with a small wave power converter with an electrolysis system for storing the wave energy in the form of the chemical components of the water: oxygen and hydrogen.

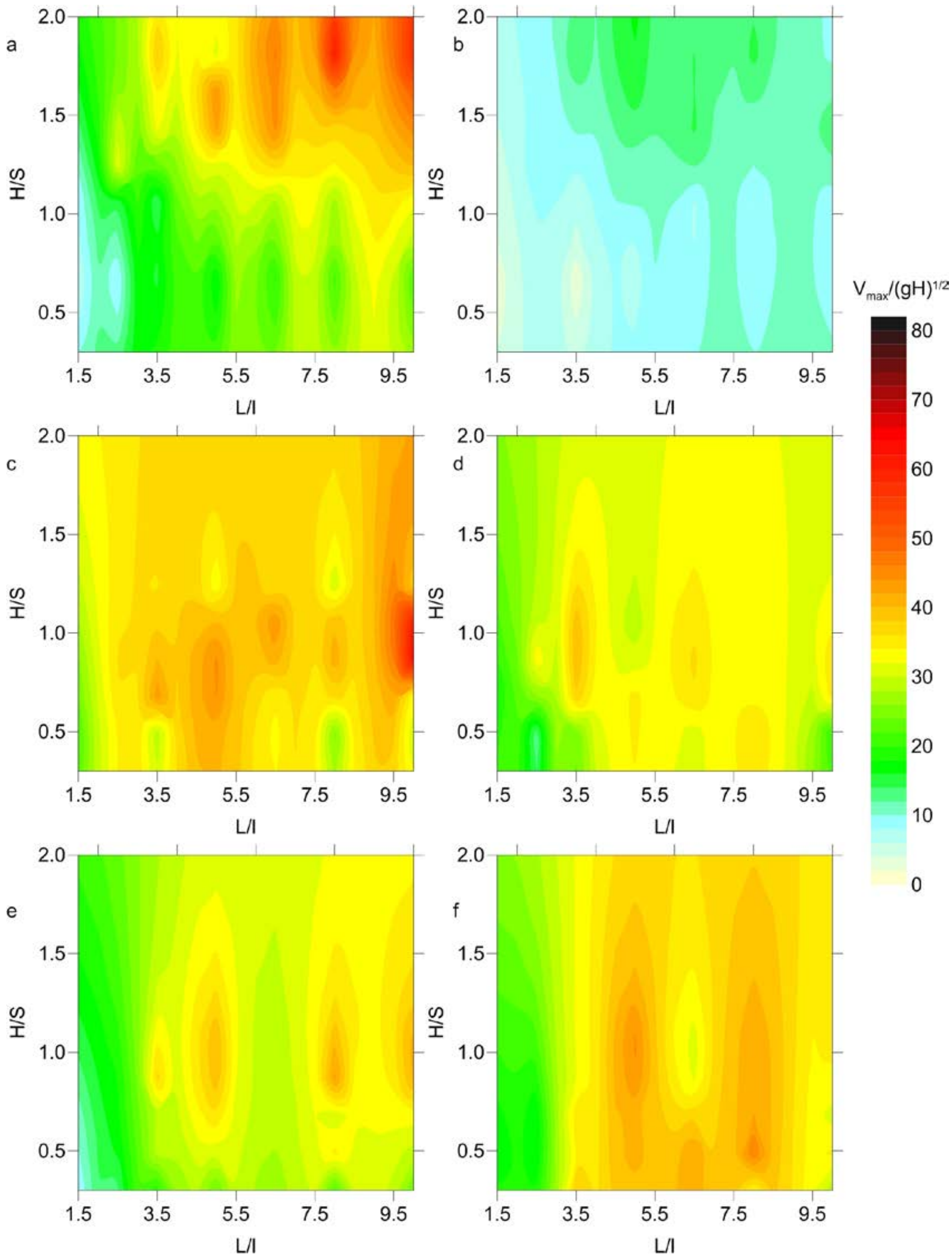

Figure 5. Dimensionless maximum velocity as a function of the normalized wavelength and relative submergence: for a) α = 0° and S_1 = 1/3, b) α = 10° and S_1 = 1/3, a) α = 0° and S_1 = 1/2, a) α = 10° and S_1 = 1/2, a) α = 0° and S_1 = 2/3, a) α = 10° and S_1 = 2/3

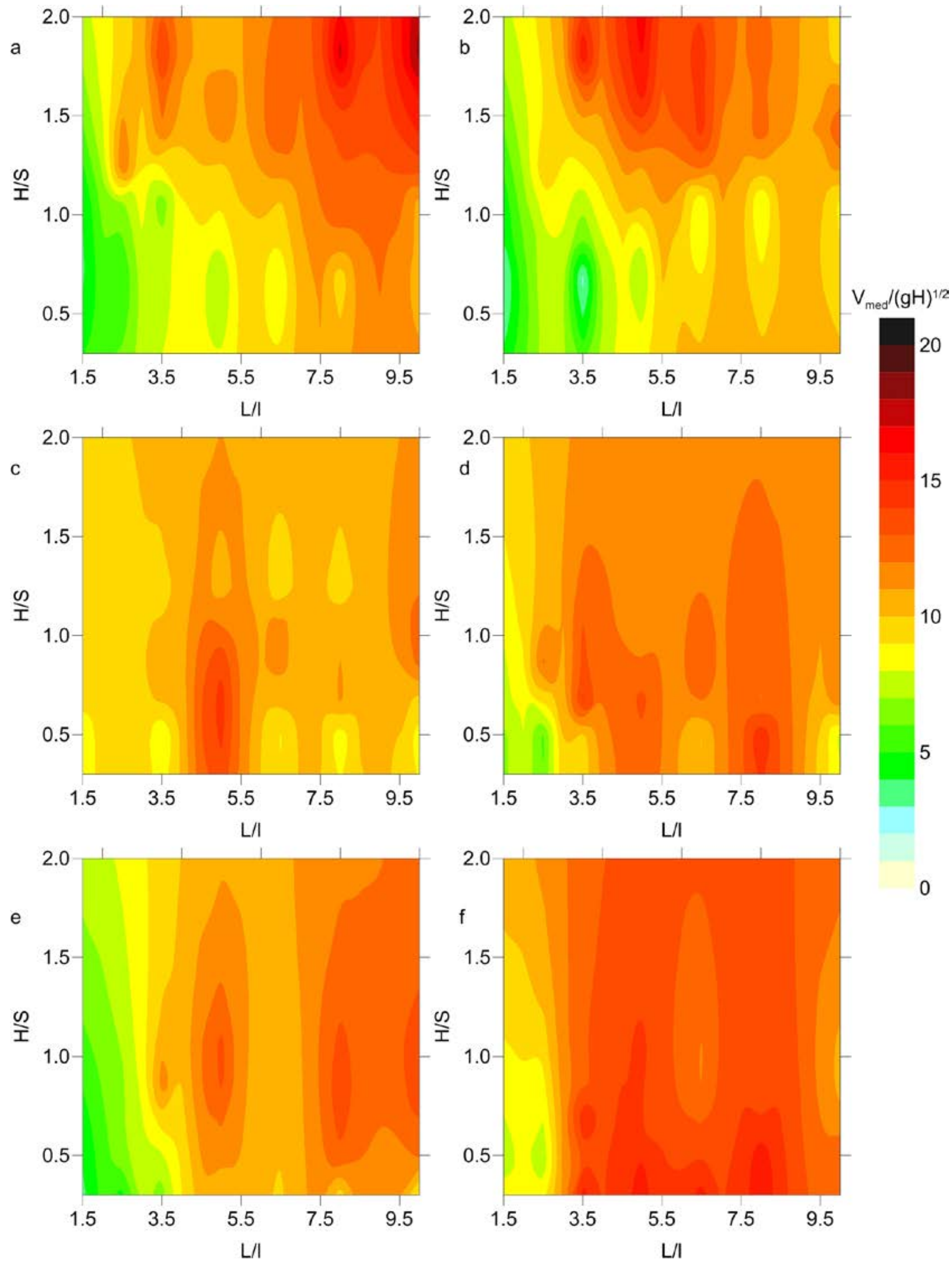

Figure 6. Dimensionless mean velocity as a function of the normalized wavelength and relative submergence: for a) α = 0° and S_1 = 1/3, b) α = 10° and S_1 = 1/3, a) α = 0° and S_1 = 1/2, a) α = 10° and S_1 = 1/2, a) α = 0° and S_1 = 2/3, a) α = 10° and S_1 = 2/3

The displayed graphs suggest a wide range of heights and periods of wave where the device emits enough energy and regular jets to suggest operating a turbo-generator.

4. Forward-looking to the mass storage of renewable energy in the form of hydrogen

Throughout history, the port protections requirement was easier to fix with dissipating the energy infrastructure of the sea as an alternative to take advantage of these unlimited resources. Projects to use of the oceans energy have arisen independently to the dissipative development protection dams of power. The *Blowjet* allows to merge the ancient techniques of break waters construction with designed devices to transform wave energy into electricity and proposing at the same time a solution to the problem posed both by Travis [20] and Bernard [45] in the sense that they are still non-existent technologies for the electricity mass storage from renewable energy sources, which prevents that they can currently replace hydrocarbons in its function of energy. Being the target capture, focus and harness the waves energy conceived as plant wave power. Vertical breakwaters profile is an extension of the *Blowjet* hydrodynamic profile as shown in Figure 7. With different concept, there is already in operational project that leverages the wave's power that has been developed in Mutriku, Spain, figure 7.
Each concrete block of the *Blowjet* is conceived in a monolithic way (its hydrodynamic profile allows it), They are moulded and fabricated on land. Each produced block are placed and armed on the seafloor joining each block with its own turbine attached to the rest of the turbines through a single axle trailer on land with a simple generator and sustained through a rails system that would allow up or down in maintenance times or accident, thereby facilitating the operations of composure change parts, general maintenance or simply let out stream in some air sound and light show. The upper end of the dyke would be no different to the constructive ways of the existing breakwater dykes.

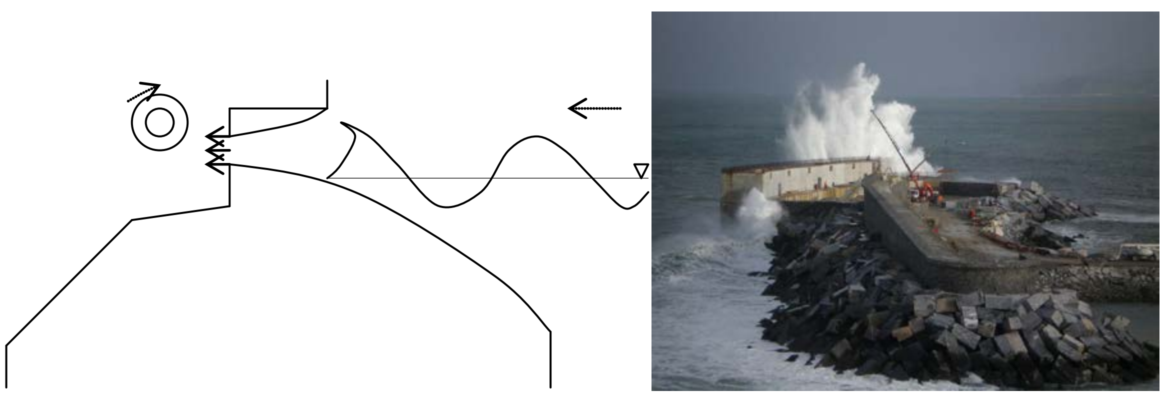

Figure 7. Breakwater-*Blowjet* and Breakwater in Mutriku, Spain [46]

4. Conclusions

The *Blowjet* is the most simple and economic transformation of waves conceived so far. The testing for characterization and linkage to a scale turbo-generator in laboratory for the breaking of the water molecule, offering both the alternative generation of electricity and its storage as hydrogen and oxygen. It is inspired by the phenomenon of "bufadora". It is a device that transforms the wave energy into kinetic energy. With the *Blowjet* it can conceive a dyke that does not dissipate the sea energy and protecting the coastal infrastructure, capture, focus and take advantage of that energy for the benefit of the protected area.

5. Acknowledgments

This work was supported by the Consejo Nacional de Ciencia y Tecnología (CONACYT) of Mexico, under project 130254 "Sistema de aprovechamiento energético del oleaje en canales en estrechamiento y su captación para la producción de hidrógeno" and by PAPIME PE104312: "Production of interactive and audiovisual teaching material in physical chemistry and thermodynamics".

6. References

[1] Şen, Z. Solar energy in progress and future research trends. Progress in Energy and Combustion Science 30(2004) 367-416.
[2] Şahin, A. D. Progress and recent trends in wind energy. Progress in Energy and Combustion Science 30(2004) 501-543.
[3] IEA. Biomass for Power Generation and CHP. Enero 2007. www.iea.org/Textbase/techno/essentials.htm
[4] Vicinanza, D., & Frigaard, P. Wave pressure acting on a seawave slot-cone generador. Coastal Engineering 55(2008) 553-568.
[5] IEA/OES, http://www.ocean-energy-systems.org/Implementing Agreement on Ocean Energy Systems, Annual Report. 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012.
[6] Fry, C. All at sea. Power Engineering, October-November (2005) 24-27.
[7] Jens Peter Kofoed, Peter Frigaard, Erik Friis-Madsen, Hans Chr. Sørensen. Prototype testing of the wave energy converter wave dragon. Renewable Energy 31 (2006) 181-189.
[8] McCabe, A. P., Bradshaw, A., Meadowcroft, J. A. C., & Aggidis, G. Developments in the design of the PS Frog Mk 5 wave energy converter. Renewable Energy 31 (2006) 141-151.
[9] Retzler, C. Measurements of the slow drift dynamics of a model Pelamis wave energy converter. Renewable Energy 31 (2006) 257-269.
[10] Bahaj, A. S., Molland, A. F., Chaplin, J. R., & Batten, W. M. J. Power and thrust measurements of marine current turbines under various hydrodynamic flow conditions in a cavitation tunnel and a towing tank. Renewable Energy 32 (2007) 407-426.
[11] Bhuyan, G. S. Harnessing the Power of the Oceans. IEA OPEN Energy Technology Bulletin Article Issue No. 52, July 2008.
[12] Mueller, M., & Wallace, R. Markus Mueller, Rubin Wallace. Enabling science and technology for marine renewable energy. Energy Policy 36(2008) 4376-4382.
[13] EOEA, European Ocean Energy Association, http://www.eu-oea.com
[14] OA, www.oceanatlas.org
[15] OP, Osmotic Power, www.stakraft.com
[16] TWP Technology White Paper on Ocean Current Energy Potential on the U.S. Outer Continental Shelf. http://ocsenergy.anl.gov
[17] Hijikata, T. Research and development of international clean energy network using hydrogen energy (WE-NET). International Journal of Hydrogen Energy 27(2002) 115-129.
[18] Verheij F., W de Boer, Quist A. The Isle of Energy: Storing power at sea. Power Engineering International, Sep 2007 48-50.
[19] Lilienthal, P. High Penetrations of Renewable Energy for Islands Grids. Power Engineering. November (2007) 90-96.
[20] Walker, T.W. Harnessing Natural Energy. Chemical Engineering Progress 104(2008) 23-28.
[21] Bağcı, B. (2009). Towards a zero energy island. Renewable Energy 34(2009) 784-789.
[22] Kaldellis, J. K., Zafirakis, D., & Kavadias, K. Techno-economic comparison of energy storage systems for island autonomous electrical networks. Renewable and Sustainable Energy Reviews 13(2009) 378-392.
[23] Dominic Michaelis, Jerome Tomasi. www.EnergyIsland.org
[24] de Oliveira Matias, J. C., & Devezas, T. C. Consumption dynamics of primary-energy sources: The Century of alternative energies. Applied Energy 84(2007) 763-770.

[25] David A. Molitor. Wave Pressure on Sea-Walls and Breakwaters. Transsactions ASCE May 1934, 984-1015.
[26] Iribarren, R. & Nogales, C. Obras Marítimas. Ed. Dossat Madrid, 1954.
[27] Andersen, T. L., Nørgaard, J. H., Ruol, P., Martinelli, L., Zanuttigh, B., Angelelli, E., Mendoza, E., Silva, R. & Enriquez-Ortiz, C. THESEUS Deliverable ID2. 5: Part B-Barriers for wave energy conversion. European Commission, 2012.
[28] Li, Y., & Raichlen, F. Energy Balance Model for Breaking Solitary Wave Runup. Journal of Waterway, Port, Coastal and Ocean Engineering. March-Abril 2003, 47-59.
[29] Peregrine, D. H. Water-Wave Impact on Walls. Annu. Rev. Fluid Mech 2003 35:23-42.
[30] Charlier, R. H., Chaineux, M. C. P., & Morcos, S. Roger H. Charlier, Marie Claire P. Chaineux, Selim Morcos. Panorama of the History of Coastal Protection. Journal of Coastal Research 21(2005) 70-111.
[31] Hsiao, S. C., Hsu, T. W., Lin, T. C., & Chang, Y. H. On de evolution and run-up of breaking solitary waves on a mild sloping beach. Coastal Engineering 55(2008) 975-988.
[32] Josset, C., Clément A. H. A time-domain numerical simulator for oscillating water column wave power plants. Renewable Energy 32(2007) 1379-1402.
[33] Duckers, L. Water power-wave, tidal and low-head hydro technologies. Power Engineering Journal August (1995) 164-172.
[34] Duckers, L. Wave power. Engineering Science and Education Journal June (2000) 113-122.
[35] Falnes, J. Review of Wave Energy Research in Norway. Wave Energy R&D. Proceedings of a Workshop held at Corck, October, 1992, European Commission EUR 15079 EN, 1993, pp. 125-128.
[36] Tjugen, A. R. TAPCHAN ocean energy proyect. Proceedings of European Wave Energy Symposium, Edinburgh, 2003, pp. 265-276.
[37] ENERGUIDE. Potensiale for Havenergiproduksjon i More og Romsdal 2007, www.rundecentre.no
[38] Leipzig, www.uni-leipzig.de
[39] Bascom, W. Waves and Beaches: the dynamics of the ocean surface. Ed. Anchor Press/Doubleday Garden City, New York 1980.
[40] Schwartz, M. Encyclopedia of Coastal Science, Ed. Springer 2005.
[41] Mendoza-Baldwin, E., Silva-Casarín, R., Sánchez-Dirzo, R. &Chávez-Cárdenas, X. Wave energy conversion using a blow-jet system. *Proceeding of 32nd International Conference on Coastal Engineering*, China (2010). Págs. 1-10.
[42] Chávez-Cárdenas, X., Sánchez-Dirzo, R., Mendoza-Baldwin, E., González-Huerta, R.G., Anaid Domínguez, M. & Silva-Casarín, R. Blow-jet: Enlace entre la energía undimotriz y la electrólisis. *Memorias del XXIV Congreso Latinoamericano de Hidráulica*,Uruguay (2010). Clave 5e_115.
[43] Chávez, X., Mendoza,E., Dirzo, R.S. & Silva, R. Diseño hidrodinámico y evaluación de un dispositivo marítimo energético, "blow-jet". *Memorias del XXI Congreso Nacionalde Hidráulica Guadalajara Jalisco*, México, octubre 2010. Clave 019.
[44] Sánchez-Dirzo R., Chávez-Cárdenas X., Mendoza-Baldwin E., González-Huerta R. de G.,Anaid-Domínguez M., Silva-Casarín R. Hydrogen from ocean energy systems. *Memorias 1er. Congreso Internacional AMIDIQ*, 2011.
[45] Lee, B. S. & Gushee, D.E. Electricity storage: the achilles' heel of renewable energy. *Chemical Engineering Progress;* Mar 2008; 104, 3; ABI/INFORM Trade & Industry.
[46] http://www.caminospaisvasco.com/Profesion/Obras/central-oleaje-mutriku/central-oleaje.