The Concept of Wastes to Energy Using Sugary Wastes

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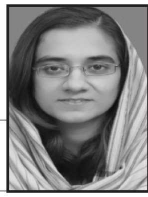

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Abstract: This study was designed using actual effluent from the sugary mills in an Up-flow Anaerobic Sludge Blanket (UASB) Reactor to evaluate treatability performance. The reactor was started-up in step-wise loading rates beginning from 0.05kg carbon oxygen demand (COD)/m^3-day to 3.50kg-COD/m^3-day. The hydraulic retention time (HRT) was slowly decreased from 96 hrs to eight hrs. It was observed that the removal efficiency of COD of more than 73% can be easily achieved at an HRT of more than 16 hours corresponding to an average organic loading rate (OLR) of 3.0kg-COD/m^3-day, at neutral pH and constant temperature of 29^{o}C. The average VFAs (volatile fatty acids) and biogas production was observed as 560mg/L and 1.6L/g-COD$_{rem}$-d, respectively. The average methane composition was estimated as 62%. The results of this study suggest that the treatment of sugar mills effluent with the anaerobic technology seems to be more reliable, effective and economical.

Key words: Anaerobic digestion, sugary wastes, carbon oxygen demand, biogas, Pakistan

Introduction

Pakistan is a water deficient country; the quantity of available water resources has been declining day by day. In 1960 it was 5654m^3/capita, by 2000 it was 1400m^3/capita and by 2010 the capacity was expected to be 1000m^3/capita (Ali, Hashmi et al 2009). The water quantity (flow rate) is decreasing day by day due to such factors as temperature, atmospheric pressure, wastage due to improper management, and pollution.

The available water in Pakistan is being polluted at an alarming rate, mainly due to untreated domestic and industrial effluents and agricultural/surface runoffs, etc. Domestic effluent includes sewage as well as sludge while industrial effluents only include waste sewage. The runoffs may include garbage and sediments. Due to all these effects of pollution, the only clean and potable water available is 18% and the remaining 82% is unfit for drinking purpose.

Besides water deficiency it is a known fact that Pakistan is deficient in energy, though it has a substantial potential of energy. The energy is not confined only to electrical energy, but bio-gas has also a significant share in this sector. However, bio-gas has not been given the attention it deserves. Biomass is an important resource in Pakistan, about 37% of total primary energy supply. The growing acceptance of anaerobic digestion at a simple, low-cost high rate and effective waste treatment technology make it a viable solution for pollution control, in addition to give support to energy resources sector.

The sugar industry plays an important role in the nation's economy. Progress in technology has been made by this industry. At the time of the Independence there were only two sugar mills, one at Rahwali in the Punjab and the other at Takhat Bai in the Khyber Pakhtun Khwa (KPK). The total quantity of sugar produced during 1947-48 was 7,932 tons. Today there are 75 sugar mills all over the country. The majority of these mills are based on sugar cane. The total crushing capacity of this industry is approximately 3.0 million tons per day.

By comparison, only four mills process beets for sugar production.

Molasses is a byproduct of the sugar manufacturing process and is exported to other countries. In Pakistan seven sugar mills convert a part of their molasses into industrial alcohol.

Pakistani sugar mills rarely exploit the possibilities of reusing wastes in the process, or as by-products. A considerable development of sucrochemistry and ethanol applications is expected in the near future. This development will bring forth problems to a scale (especially associated with pollution by aggressive molasses and vinasses) that makes the current problem appear insignificant (Pak-EPA 1999).

In order to secure the environment from the adverse impacts of untreated industrial effluent, it is necessary that all the waste water be treated as an integral part of their production before discharging the wastes into the receiving streams or rivers. Because Pakistan is facing an acute shortage of energy it is encouraging the technologies like UASB (Up-flow Anaerobic Sludge Blanket) Reactor technology will not only prevent water pollution but can help tackle the problem of the energy crises to a certain extent. For the treatment of sugar mills effluent the anaerobic technology seems to be reliable, effective and economical. Hence, a long-term comprehensive study is required to investigate the treatment feasibility of sugary wastes in a single-stage UASB reactor.

The main objectives of this study are to evaluate the treatability performance of sugary wastes usage under anaerobic conditions and to estimate the amount of biogas production from sugary wastes using a UASB reactor.

Materials and Methodology

Experimental UASB reactor

Due to the advantages and high application potential of the UASB reactor for developing countries, it was decided to employ a UASB reactor for this study. A UASB reactor made up of acryl resin material with a total effective volume of 8.0 liters was used. It consisted of a reaction portion of 6.2 liters and a settling tank portion of 1.8 liters. The internal diameter of the reactor was eight centimeters and the thickness of the water jacket was 1.5 centimeters. The reactor had a water jacket to maintain a constant temperature of 29±0.50C. The reactor was also equipped with a gas solid separator (GSS) and a mixer (Ali and Hashmi 2010). The systematic diagram of the UASB reactor is shown in the Figure 1.

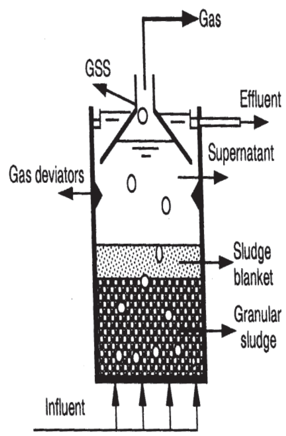

Figure 1 : UASB Reactor

Substrate and Nutrients

Actual domestic sewage was used as the sole carbon source in the feed (influent). Nitrogen and phosphorous were added in the form of (NH4)2SO4 and KH2PO4 in accordance with the carbon oxygen demand (COD):N:P ratio of 550:5:1. Trace nutrients were added at a concentration of 1.0 milliliter/liter after making a stock solution of nutrients in the following concentration, as shown in Table 1.

Table 1. Trace Nutrient Concentrations

Trace Nutrient	Concentration (mg/L)
$FeCl_3.6H2O$	5.2
$CoCl_2.6H_2O$	0.35
$ZnSO_4$	0.28
$CaCl_2.2H_2O$	0.31
$CuSO_4$	0.86

Seed Sludge

Seventy percent of the UASB reactor was seeded with an anaerobic digester and activated sludge from the nearby waste water treatment plant. The characteristics of the seeded sludge under the startup condition of the reactor are shown in Table 2. The acclimatization process continued for about two to three weeks in the laboratory. The seed sludge provided 42 grams of volatile suspended solids (VSS). The loading rate was increased stepwise in order to avoid organic loading shocks. Hydraulic retention time (HRT) was also studied. Mixing was done twice a day.

Table 2. Characteristics of Seeded Sludge

Parameters	Value
Total Solids, TS (mg/L)	74.80
Total Suspended Solids, TSS (mg/L)	51.66
Volatile Suspended Solids, TVS (mg/L)	39.80
Color	Blackish

Operational Conditions

The reactor was started-up in step-wise loading rates starting from 0.05kg-COD/m^3-day to 3.50 kg-COD/m^3-day. The HRT was slowly decreased from 96 to 08 hours at constant neutral pH and mesophilic temperature.

Monitoring and analysis

pH, temperature, influent and effluent COD, VFAs and gas production were monitored regularly, twice a week. Gas was collected over a tap water saturated with NaCl. All analyses were carried out according to standard methods (APHA/AWWA/WEF 2005).

Results and Discussion

During the study the COD removal efficiency and the gas production was observed for various organic loading rate (OLR) and HRT at constant temperature and pH.

Start-Up of the reactor

pH is the most important and principle operational parameter of anaerobic digestion. An optimum pH of "5.5 to 6.0" was reported for the process of anaerobic digestion in UASB (Lettinga, Velsen et al 1980). Since the methanolic bacteria are highly sensitive to pH and require neutral pH conditions, this range seems to be unsuitable for the optimum growth of this kind of bacteria (Bhatti 1995). It was concluded that 7.8 is the optimum pH, with no activity occurring below pH 6.8. These results suggest that optimum pH should lie within neutral condition pH. This concept is also supported by Bhatti (1995).

Therefore, in our study we tried to maintain the pH of the reactor near to neutral by adding an external buffer in the form of NaHCO3 to the feed solution. The course of reactor pH during the experimental period, the effect of reactor pH on COD removal efficiency of the UASB, the formation of VAFs in the effluent, and the amount of biogas production are shown in the Figures 2 to 5.

The pH of the reactor was highly alkaline; i.e., 8.7; but became acidic after two to three weeks of operation, and varied from 5.9 to 6.5. It was later controlled at around neutral pH after the seventh day by the addition of 60ml of 0.5M (Mole) $NaHCO_3$ per liter of the feed solution. During the neutral pH phase, high bicarbonate alkalinity of more than 1500 mg-$CaCO_3$/L was observed, and that was initially less than 200 mg-$CaCO_3$/L when there was no addition of external buffering in the form of $NaHCO_3$.

The effect of pH on the COD removal efficiency shows that about 70% of the COD can be removed, if the pH of the reactor is kept neutral. Thus, by keeping the pH of the reactor at about 7.0, the effluent COD can be easily dropped down to the limits set by Pak-EPA NEQS (National Environmental Quality Standards). VFAs are one of the important parameter that shows the inefficiency of the reactor to convert acetic acid into methane.

In this study, the formation of VFAs was observed to be 560mg/L (average value of the study). The maximum formation of VFAs (680mg/L) was observed when the pH of the reactor was about 6.3. Corresponding to this pH only 49% of the COD was observed to be removed.

Treatability Performance of the Reactor

The treatment COD removal efficiency of the UASB was observed to be greatly dependent on HRT and OLR, at constant pH and temperature. The effects of OLR and HRT on the COD removal efficiency are shown in the Figures 6 and 7. The longer retention time seems to be more favorable in terms of COD reduction.

During an earlier stage of the experiment, when the HRT was high, the COD reduction was observed to be more than 76%. At the sixth week the COD observed was the least, about 48% at an average HRT of 56 hours, due to the excessive accumulation of VFAs in the system and drop of pH to 5.9. The maximum COD (73%) was observed in the twelfth week, when the average HRT was 16 hours and the OLR was observed to be 3.0kg-COD/m^3-day, and the pH of the reactor was about 7.2. This indicates that pH greatly influences the performance of UASB reactor.

The removal efficiencies of total carbon oxygen demand COD achieved are in the range of 51 to 74% (Vieira 1988; Schellinkhout 1993; Seghezzo, Zeeman et al 1998). The reactors are operated at ambient temperatures (18 to 32°C) and OLRs in the range of 0.9 to 3.55kg-COD/m^3-day. The study shows a close resemblance in the results; i.e., the average COD removal was observed to be 69% at an average temperature of 29oC and an average OLR of 2.5kg-COD/m^3-day.

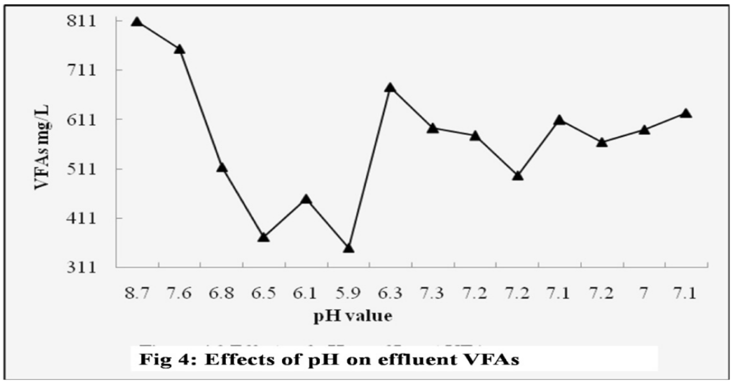

Figure 4. Effects of pH on Effluent VFAs

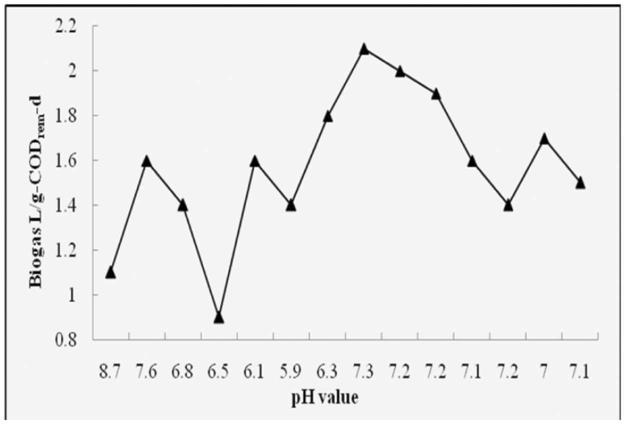

Figure 5. Effects of pH on Biogas Production

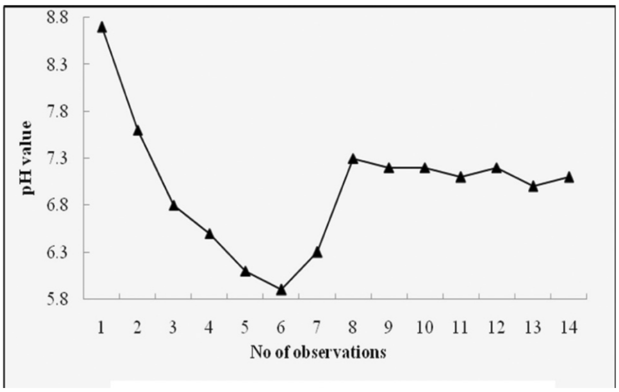

Figure 2. Time Course of pH During the Study Period

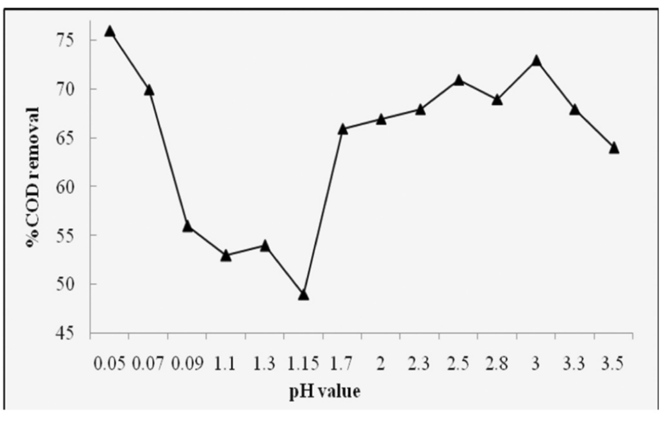

Figure 3. Effects of pH on COD Removel Efficiency

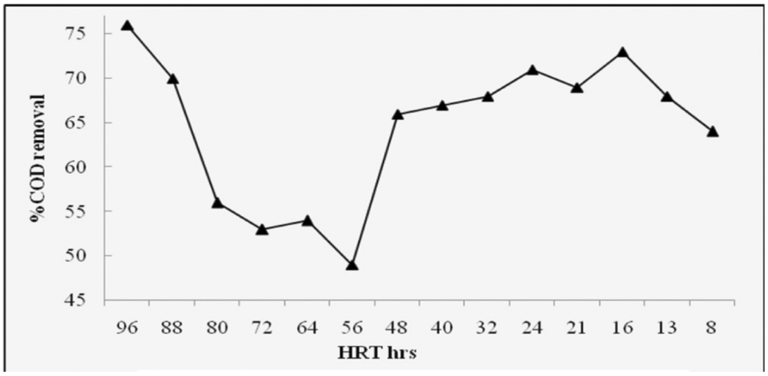

Figure 6. Effects of pH on Biogas Production

It was observed that for every step there was an increase in the COD removal efficiency of the reactor after establishing steady state conditions under a given OLR. And in every step of increasing the OLR, it was observed that there was an abrupt decrease in the COD removal efficiency due to the increase in concentration of VFAs in the reactor and heavy organic shocks.

The low peaks of efficiency observed during the sixth week in the beginning could be attributed to the variation in flow and acclimatization of seed sludge to the waste. For fulfilling the requirement of Pakistan's NEQS, the removal efficiency of COD of more than 73% can be easily achieved at an HRT of more than 16 hours and an average OLR of 3.0kg-COD/m^3-day, and maintaining the pH and temperature of 7.2 and 29oC, respectively.

Biogas Production in the Reactor

Small gas bubbles were observed from the start of the experiment. The gas was collected in a smaller system saturated with NaCl solution. However, because of low gas pressure the gas production rates and deficiency in

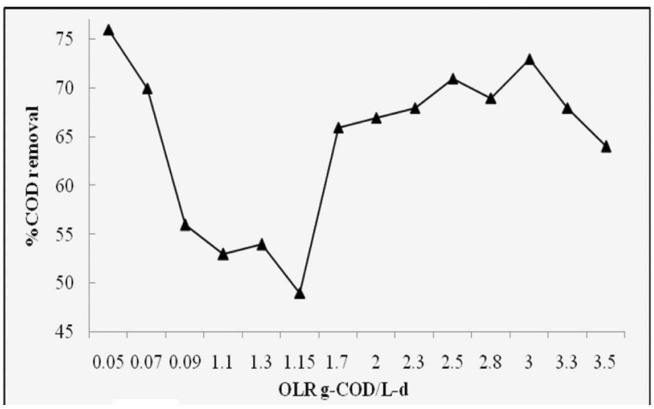

Figure 7. Effects of OLR on COD Removal Efficiency

the gas collection system, appreciable amounts of gas could not be collected until the second week. Methane (CH4) content of 75 to 80% of the gas is reported by Bhatti (1995) and a study on dairy waste has shown it to be 75%. The rest of the gas content will be mainly CO2, because these two gases are produced in the anaerobic digestion process. A portion of the gas could be H2, if the system is not working properly due to the presence of hydrogen-producing acetogens, which provide unfavorable conditions for the conversion of VFAs to acetate then to methane. The results of the study are shown below in Figure 8.

The low gas production of 0.85L/g-CODrem-d was observed on the fourth day when the concentration of VFAs was found to be about 621mg/L. This indicates that the population of methanogenic bacteria had not grown appreciably and that facultative microbes may be competing for the sub-

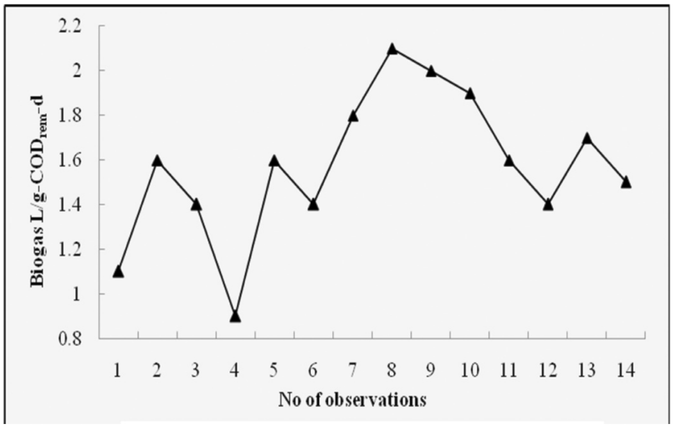

Figure 8. Time Course of Biogas Production

strate with the methane producing organisms.
An average gas conversation rate was calculated to be 1.6L/g-CODrem-d, whereas, the estimated percentage concentration of methane and carbon dioxide was observed as 62% and 37%, respectively.

Table 3. Observations and Calculations

Flow rate, m^3/hr	210
Chemical Oxygen Demand, mg/L	2850
Biochemical Oxygen Demand, mg/L	2050
Total Suspended Solids, mg/L	760
Total Volatile Suspended Solids, mg/L	580
Velocity m/hr	0.5
Depth, m	5.0

Table 4. Reactors Configurations

Dimensions, Dia x H	24m x 5m
Hydraulic Retention Time, HRT	16 hrs
Volumetric Loading Rate, VLR	6.30 kg-COD/m^{3}-day
Gas production	16644m^3
CH_4 production	8654.88m^3
Total sludge production	3536 kg/day

Conclusions and Recommendations

Reactor Design Based on Laboratory Results

- Therefore, hydraulic retention time based on the observed parameters,
  tD = Depth/velocity = 5/0.5 = 10 hrs
  (Ok! because the optimum observed value is 16 hrs)
- Calculating the volume of the reactor, V = tD x Q = 10 hrs x 210 m^3/hr = 2100 m^3
- Surface area, A = V/H = 2100/5 = 420 m^2
- Calculated diameter for the reactor, Dia = 23.13 m, say Dia = 24.0 m
- Actual surface area, A = 452.16 m^2, based on 24.0 m diameter reactor.
- Actual volume, V = 2260.80 m^3, based on 24.0 m diameter reactor.
- Check, volumetric loading rate, VLR
  COD applied = 2.85 kg/m^3 x 5000 m^3/day = 14250 kg/day
  VLR = COD applied/volume of the tank = 14250/2260.80 = 6.30 kg-COD/m^3-day
  (Ok! Because the theoretical VLR = 6-20 kg-COD/m^3-day)
- Optimum COD removal observed = 73%
- Total COD removal = 0.73 x 14250 = 10402.50 kg/day
- Total biogas production = 1.6 m^3/kg-CODrem-d x 10402.50 kg/day = 16644m^3
- Amount of methane production = 0.62 x 16644 = 8654.88 m^3
- Amount of sludge produce during the process = a + b + c,
  Where, a = (15-18) % BOD removed
  b = (40-50) % of non-biodegradable portion of VSS
  c = TFS
  ..... = 1476 kg/day + 1160 kg/day + 900 kg/day = 3536 kg/day

1. Treatment of sugary wastes is technically feasible provided that the pH of the system is kept near to neutral. This can be achieved by adding NaHCO3 to the feed solution.
2. The volumetric loading rate of 3.0 kg-COD/m^3-day and an HRT of more than 16 hours are the conservative figures that warrant a removal efficiency of more than 73%; thus, for practical purposes the UASB reactor for sugary wastes could be designed to operate under optimum condition to given acceptable COD removal as per the Pak-EPA limitations.
3. With a reactor of 24.0 meter diameter and 5.0 meter depth, if used for the treatability of sugar mills effluent; an estimated amount of 16,000m3 of biogas per day could be produced, if the wastewater discharge from the mill is about 210m^3/hr with COD concentration of 2850mg/L.
4. Since Pakistan is facing a shortage of energy, encouraging such technologies can help tackle the problem of energy crises.

Based on this study it is recommenced that a comprehensive and long term study is required to study the exact behavior of a UASB reactor for sugary wastes under variable environmental conditions. Moreover, the cost of developing the UASB technology for the larger basis needs to be focused.

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CALENDAR OF EVENTS

Drinking Water

21-27 August, 2011: World Water Week, Stockholm, Location: Sweden. More info: http://worldagroforestry.org/projects/searnet/index.php?id=28&EventID=25.

19-23 September, 2011: First International Sustainable Watershed Management Conference (SuWaMa), Location: Istanbul, Turkey. More info: http://worldagroforestry.org/projects/searnet/index.php?id=28&EventID=27.

19-21 October, 2011: WaterMed 2011, Location: Milan, Italy. More info: http://www.watermed.com/en_wtm/index_wtm.asp.

24-25 October, 2011: 2011 OU International Water Conference and Water Prize Award Ceremony, Location: Norman, Oklahoma, USA. More info: http://www.water.ou.edu.

25-27 April, 2012: First International Conference on the Design, Construction, Maintenance, Monitoring and Control of Urban Water Systems, Location: New Forest, United Kingdom. More info: http://www.wessex.ac.uk/12-conferences/urban-water-2012.html.

Energy

5-7 August, 2011: Fifth International Workshop on Natural Energies (IWONE 2011), Location: Sweden. More info: http://www.iet-community.org/iwone/IWONE5/

12-14 August, 2011: 2011 International Conference on Energy and Electrical Systems (ICEES 2011), Location: Kuala Lumpur, Malaysia. More info: http://www.icees.org/

4-7 September, 2011: 10th International Conference on Sustainable Energy Technologies, Location: Istanbul, Turkey. More info: http://www.set2011.org.

15 September, 2011: International Conference on “Best Practices in Distribution”, Location: India. More Info: www.cbip.org.

20-22 September, 2011: Jordan International Energy Conference, Location: Amman, Jordan. More info: http://www.jeaconf.org/jiec2011/index.html.

27-29 September, 2011: Renewable Energy World Asia, Location: Kuala Lumpur, Malaysia. More info: http://www.renewableenergyworld-asia.com.

27-30 September, 2011: 2011 IEEE International Conference on Smart Grid and Clean Energy Technologies (IEEE ICSGCE 2011), Location: Chengdu, China. More info: http://www.icsgce.com/

7-19 October, 2011: World Renewable Energy Congress-Indonesia: The International Conference and Exhibition on Renewable Energy and Energy Efficiency, Location: Bali, Indonesia. More info: http://www.wreeec2011bali.com.

12-14 October, 2011: International Conference on Sustainable Development through Renewable Energy Technology, Location: Kathmandu, Nepal. More info: http://www.retrudconference.com/index.php/returd/retrud2011; Contact: ces@ioe.edu.np

14-17 November, 2011: The 2011 International Conference on Water, Energy, and the Environment, Location: Sharjah, United Arab Emirates. More info: http://www.aus.edu/conferences/icwes/

15-17 November, 2011: WATEC Israel 2011, The 6th International Exhibition and the 3rd International Conference on Water Technologies, Renewable Energy and Environmental Control, Location: Tel Aviv Exhibition Centre, Tel Aviv, Israel. More info: http// www.watec-israel.com.

16-17 November, 2011: Biofuels International expo and Conference, Location: Antwerp, Belgium. More info: http://www.biofuelsinternationalexpo.com/

20 - 24 November, 2011: 2011 WEC Executive Assembly; Further details to follow; Location: Oran, Algeria. Contact: Deborah Best, Manager, Governance Processes; More info: http://www.worldenergy.org/about_wec/executive_assembly/oran_2011/default.asp; contact: best@worldenergy.org.

24-26 November, 2011: Electric Power Engineering and Control Systems 2011 (EPECS-2011), Location: Lviv, Ukraine. More info: http://epecs.ukrscience.org/en.

20-22 December, 2011: Third International Renewable Energy Conference, Location: Hammamet, Tunisia. More info: http://www.irec.cmerp.net.

4-6 January, 2012: International Conference on Renewable Energy Utilization (ICREU 2012), Location: Coimbatore, Tamilnadu, India. More info: http://www.icreu2012.com.