OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

20917

PROJECT PROPOSAL

MOROCCO

The application of Biogas Technology to the treatment of industrial waste in Morocco

Report carried out on behalf of the United Nations Industrial Development Organization

January 1994
Danish Technological Institute
Carl Bro Environment A/S

PROJECT 1

Treatment of waste water from the sugar industry

The following project proposal includes a waste water system treating the waste water from the sugar factory SUNAG 2 and SOTRAMEG using a UASB reactor system. The two plants are located close to one another in a rural district with 20.000 inhabitants who all are using the surface water from the Sebou River for irrigation and underground water for drinking water. The SUNAG 2 plant has a capacity for treating around 300,000 tonnes of sugar beets per year during the harvest period from mid May to mid August. During this period the waste water from the sugar plant amounts to 200 m^3 per hour.

The SOTRAMEG is located as neighbour to SUNAG 2 and produces about 5.000 m^3 of alcohol based upon melasses from SUNAG 2 and other sugar factories. The waste water from the fermentation and destillation is about 10 m^3 per hour and the plant is working 8 - 10 months per year.

The aim of the project

At the moment the waste water is released in the Sebou River. The aim of the project is to create a situation where the pollution that today corresponds to the waste from a city with more than 200.000 inhabitants, is heavily reduced. Improvement is done through anaerobic degradation of the organic matter in waste water using a system of UASB reactors.

Project description

The industry in general

In Morocco there are 13 sugar plants treating both sugar cane and sugar beets. The installed capacity in each of the plants can be seen in the Table below. These plants can treat 3,4 million tonnes of sugar beets and 1,2 million tonnes of sugar cane per year. This corresponds to a maximum sugar production of about 550.000 tonnes per year. During the years from 1988 - 1990 the average yearly production nearly has been 480.000 tonnes. The sugar consumption in Morocco in these years have been 730.000 tonnes. This means that Morocco imports approximately 33 % of the sugar needed for domestic consumption. Much sugar is used in the traditional Moroccan kitchen and the sugar demand has more or less doubled from the year 1960 to 1990. The first sugar plant in Morocco came into production in 1963 and some of the plants are quite new. The newest is from 1982. Due to a relatively low price of sugar on the world market there are no immediate plans for construction of new units.

Sugar factories in Morocco

	Sugar factories	Location	Establisment/ date	Daily capacity app.
GHARB	SUNAB	SIDI SLIMANE	1963	3000 t(B)
	SUNAG/KSIRI (SUNAG 2)	MECHRAA BEL KSIRI	1968	4000 t(B)
	*SUNAG/TAZI (SUNAG 2)	SIDI ALLAL TAZI	1968	4000 t(B)
	SUNACAS	MECHRAA BEL KSIRI	1975	2500 t(C)
	SURAC	DAR EL GUEDDARI	1981	3500 t(C)
TADLA	S U T A	SOUK ES SEBT	1965	3600 t(B)
	S U B M	BENI MELLAL	1969	4800 t(B)
	S U N A T	OULAD AYAD	1971	6000 t(B)
DOUKKALA	DOUKKALA	SIDI BENNOUR	1970	4000 t(B)
	ZEMAMRA	KHEMIS DES ZEMAMRA	1982	4000 t(B)
LOUKKOS	SUNABEL	KSAR EL KEBIR	1978	4000 t(B)
	SUCRAL	LARACHE	1984	3500 t(B)
BASSE MOULOUYA	SUCRAFOR	ZAIO	1972	3000 t(B) 1000 t(C)

B = sugar beets
C = sugar.cane

Project proposal

The proposed project description includes a combined treatment unit for the waste from SUNAG 2 sugar plant and the SOTRAMEG distillery. The SUNAG 2 plant was constructed in 1968 and has an installed capacity for treating 4.000 tonnes per day. The sugar production based on 300.000 tonnes of sugar beets is 45.000 tonnes of sugar, 18.000 tonnes of pulp and 26.000 tonnes of melasses. The waste water from the sugar plant amounts to 200 cubic metre per hour during the campaign. Approximately 150 cubic metre of water is taken in per hour, the rest is comes from the sugar beets during the process. This is naturally quite a substantial amount of waste water. The COD in the waste water is about 3.500 milligrams per litre.

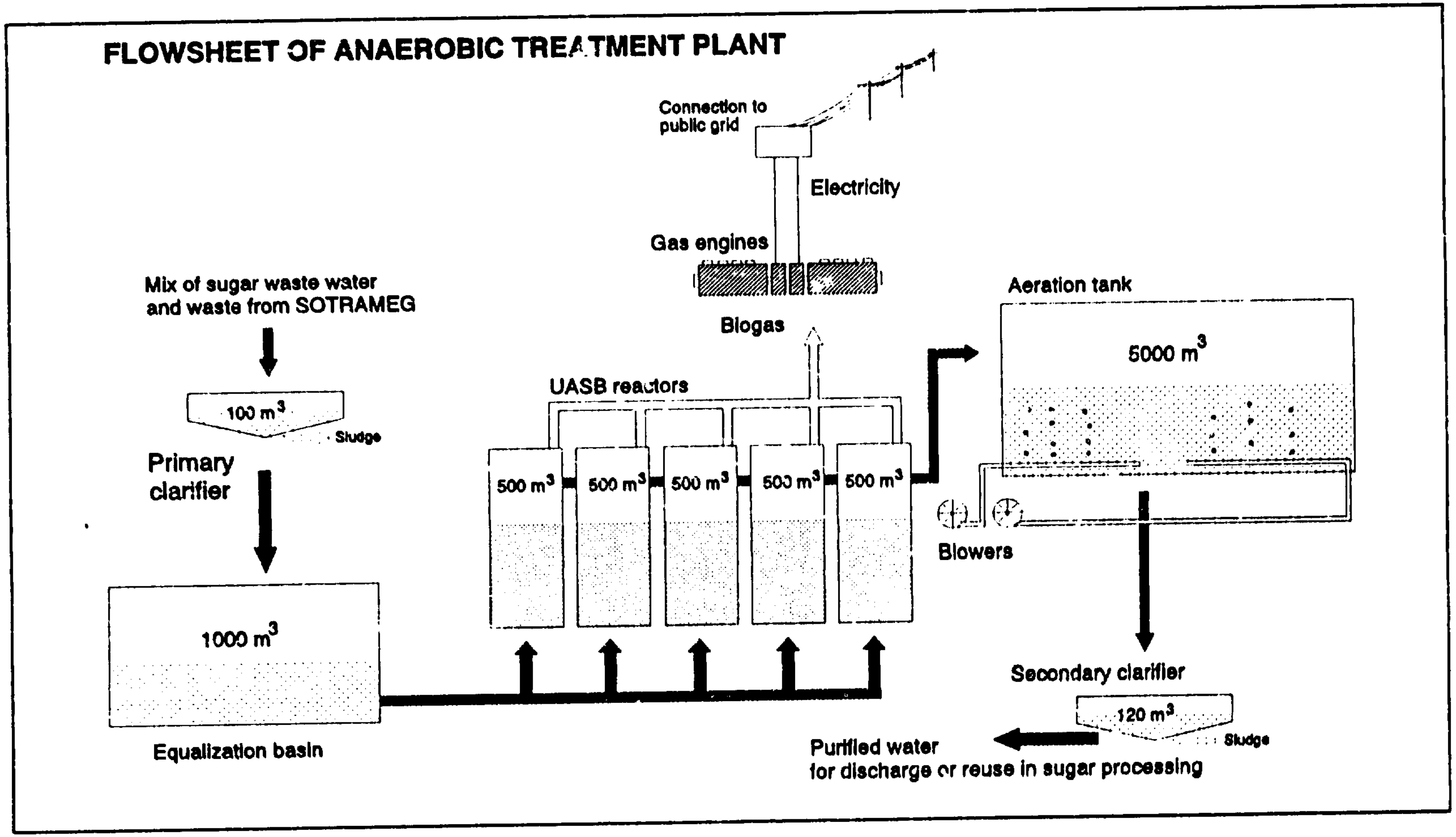
The plant uses coal for heat production and during the campaign approximately a total of 21.000 tonnes of coal is used. Some of the steam is used for electricity production. The plant itself has an installed electricity production unit with a capacity of 6 MW. At present all waste water from the plant ends in the Sebou River without treatment.

SOTRAMEG is the sole distillery in Morocco. It is located as a neighbour to SUNAG 2. It is, however, an independent company but both SUNAG 2 and SOTRAMEG are government owned. It produces about 5.000 cubic metre of alcohol per year based upon melasses received from SUNAG 2 and other sugar factories. The waste water from the fermentation and destillation is about 10 cubic metre per hour and the plant is working 8 - 10 months a year. The waste water has a very high concentration of COD i.e. 60.000 milligramme per litre.

Untreated waste water is collected in large basins close to the plant. This practice has led to odour nuisances and pollution of neighbouring wells. The waste water eventually ends up in the Sebou River.

System design

As it can be seen from the figure below, the waste water from the SUNAG 2 and SOTRAMEG could treat in a UASB reactor system with a reactor volume of 2.500 m^3. The waste water pass a primary clarifier and a equalization basin before it is going to the UASB reactors. The waste water from the UASB reactor pass an aeration tank before it, via a secondary clarifier, can be reused in the sugar plant. During the period where only SOTRAMEG operates, only one of the UASB reactors is used and a system for diluting the waste water from SOTRAMEG plant must be established before it comes to the UASB reactors. During the peak period the waste water will consist of a mixture of 200 m^3 with 3,5 kg/m^3 of COD and 10 m^3 with 60 kg/m^3 of COD giving 210 m^3 with 6,2 kg/m^3 of COD. This will give about 12.000 m^3 CH_4 per day. This again corresponds to 1,8 MW if it is used for electricity generation and at the same time about twice that amount of heat.



FLOWSHEET OF ANAEROBIC TREATMENT PLANT
Connection to public grid
Electricity
Gas engines
Mix of sugar waste water and waste from SOTRAMEG
Biogas
Aeration tank
5000 m3
UASB reactors
100 m3
Sludge
Primary clarifier
500 m3
500 m3
500 m3
500 m3
500 m3
Blowers
1000 m3
Secondary clarifier
120 m3
Sludge
Equalization basin
Purified water for discharge or reuse in sugar processing

Project plan

Phase 1

This phase will include a detailed examination of the flow of water and materials through the different processes in the industry. Detailed chemical analysis will be carried out at different stages of the process. Determination of the water quality requirement will also be carried our at different stages of the process. The investigation shall be carried out in close co-operation with the Institut Agronomique et Veterinaire Hassan II (IAVH). The report made by Fondation Universitaire Luxembougeoise with analyses of the waste water from the Gharb sugar plant form a good input to this field.

Phase 2

Elaboration of detailed plans, the demonstration plan including system design plans for use of energy (CH_4) and the produced heat and electricity as well as reuse of water. The system design should be based on tests carried out in Europe and at IAVH.

Phase 3

Implementation of a full scale demonstration unit at SUNAG 2 and at SOTRAMEG.

Investment budget

a. Planning services	USD 420.000
b. Construction services	USD 210.000
c. Commissioning services	USD 220.000
d. Management and control during design, construction and commissioning	USD 245.000
Total planning services	USD 1.095.000
Investment per plant	
Site preparation	USD 100.000
Construction works	USD 340.000
UASB reactor system	USD 850.000
Aeration tank system	USD 800.000
Clarifier	USD 110.000
Equalizing basin	USD 80.000
Gas motors	USD 1.200.000
Pumps, blowers, screens and other major components	USD 180.000
Piping	USD 250.000
Control system	USD 210.000
Connection to grid	USD 380.000
Subtotal	USD 4.500.000
Total	USD 5.595.000

The project is suggested financed as a demonstration project with 33 % by SUNAG 2 and SOTRAMEG and 33 % by national and the remaining 34 % by international donors

Project 2

Treatment of waste from the industry for conservation of fish

Introduction

Processing of fish from raw materials to consumers products requires a great amount of freshwater, which after the processing contains high levels of organic matter and nutrients. Today, most of this water is discharged directly to the sea of waterways without any kind of purification, thereby contributing to the pollution of the sea.

Using this practice of water management causes an unwanted environmental load and an unsuitable exploitation of the water resources.

Therefore, the local authorities as well as the involved industries have shown a great interest in finding new and environmentally reasonable solutions to those problems. Besides this, there is also an economically benefit for the industry in reusing water and to produce energy for its own consumption.

The organic matter in the process water from fish processing mainly consists of dissolved organic matter, such as methylamine, volatile and nonvolatile fatty acids, aminoacids, together with suspended particular matter, fats and oils. The pH level is within the area of bacterial growth and the temperature is optimal for growth of mesophile microorganisms.

Aim of the project

The aim of the project is to set up a demonstration unit in a fish processing industry and thereby avoiding an important pollution of the area around the industry and at the same time using the heat and biogas to replace conventional energy.

The improvement is done through anaerobic degradation of the organic matter in the waste water using an UASB reactor, combined with a nitrification/denitrification system and biological removal of phosphorus. The removal of nitrogen and phosphorus is actually done by the energy bound in the organic matter of the process water, excess organic matter is converted to methane.

Project description

The industry in general

Morocco has a very long coast line (about 3000 km) and the fishing industry has always been a very important industry for Morocco. It is one of Morocco's major export industries and there has always been an important industry in Morocco, in the fish conserves sector. The most important fish being treated are sardines, mackerels, anchovies and tuna.

According to the statistics of 1993 the fishing industry includes 64 conserving plants. The most important are to be found in the cities of Safi (50 %) Essaouira (11 %) and Agadir (34 %). The theoretic capacity of these installations are approximately 1.600 tonnes of fish per day. Given a year with approximately 250 working days this gives a total yearly capacity of these 64 plants of 400.000 tonnes of fish. During the years 1980 - 1989 the actual number of tonnes treated has been 103.000 tonnes yearly.

When treating the fish the head is cut off, and the blood and part of the intestines are washed out with the waste water. The actual amount of the fish that is being used is for conserves varies among the fish species. In the case of the sardines measurements show that approximately one third of the actual weight of the fish when caught is ending in the conserves. Another third is cut off and can be regarded as semi solid waste, head etc. The remaining third of the fish weight when caught is washed away with the waste water. As mentioned the amount of fish being used varies. Statisticly one can calculate that in the years 1980 - 1989 the weight of the fish in the conserves was around 51.000 tonnes per year. With an input of 103.000 tonnes this means that about 50 % of the fish treated ends up as waste, either in the waste waster or as semi solid waste.

The demonstration plant

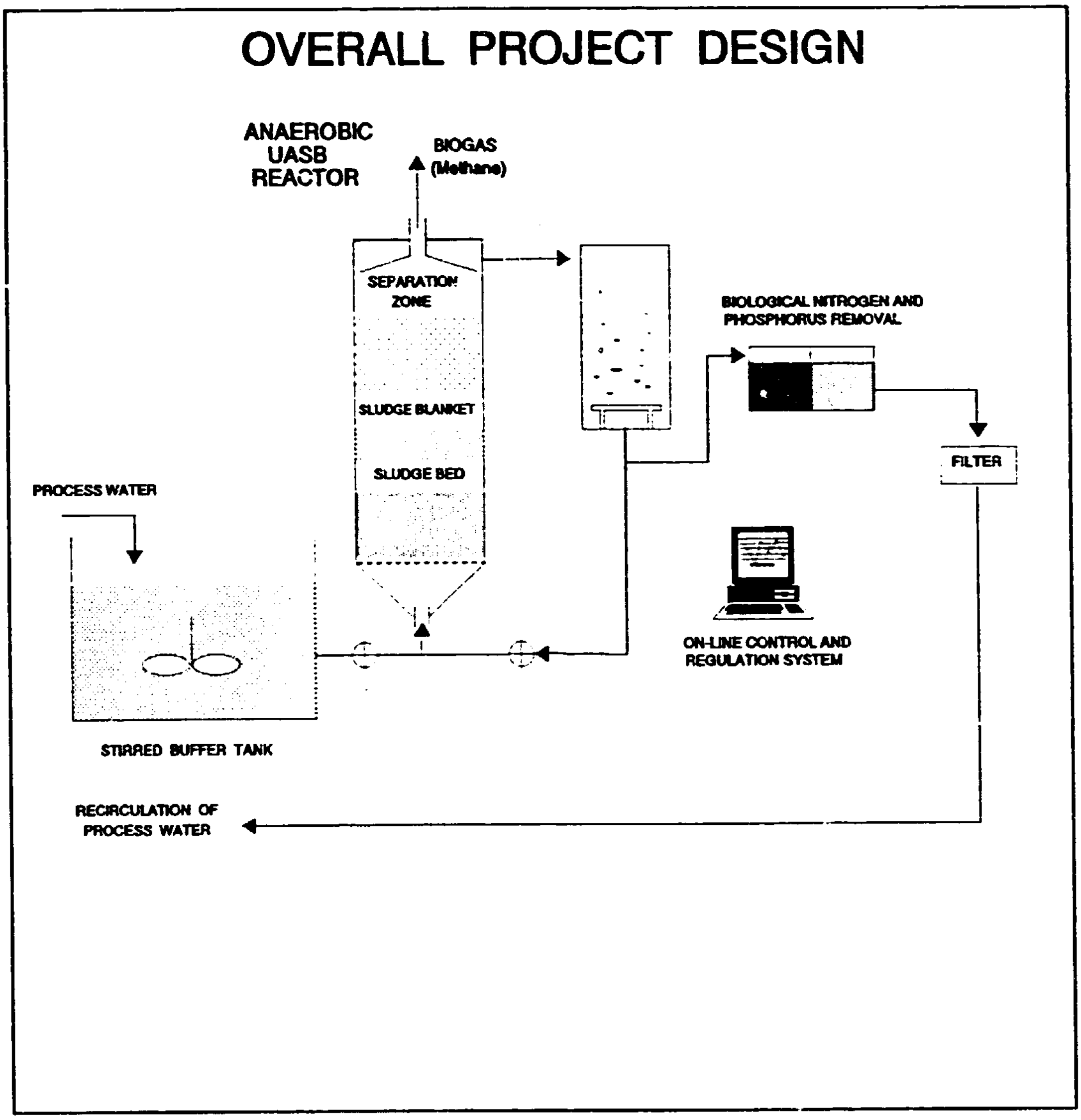
In order to evaluate the possibility for using the waste from the fish conserves industry, an investigation has been made by using input from a specific fish conserves industry, Espadon, placed in Agadir. This plant process between 3.200 - 4.000 tonnes of fish each year. According to the plant manager the plant operates normally 120 days per year. The treatment of fish can be seen from the Table below. Out of the 3.600 tonnes per year only 1.200 tonnes end up as canned fish (10 tonnes per day). The rest can be divided in around 10 tonnes per day that are washed out with the approx. 60 m^3 of waste water.

3600 t/y fish

1200 t/y	1200 t/y	1200 t/y
used	in the waste water	semi solid
↓	↓	↓
10 t/day	10 t/day in 60m^3 water	sold to a fish oil plant for 22 CDH/kg

The semi solid part, the heads etc. around 10 tonnes a day, is sold to a fish oil plant nearby for 22 CDH per kilo. The COD of the waste water is around 20.000 milligrams per litre. If this waste water was treated in an UASB reactor, it could give a production of approx. 500 m^3 of methane per day. At present this waste water is deposited directly into the bay of Agadir, which is a major tourist resort. In the plant itself about 120 tonnes of fuel oil is used per year and the costs of the fuel oil is around 450.000 DH. The electricity cost 150.000 DH and water 100.000 DH. Altogether 700.000 DH or approximately USD 73.000. If the total semi solid waste was crushed and sent with the waste water through the UASB reactor the amount of methane production could be doubled to an amount of 1.000 m^3 of methane per day. This more or less corresponds to the total need for fuel oil in the plant. Furthermore the waste water that has passed the UASB reactor could be reused in the process.

Laboratory investigations of the actual composition of process water and sludge produced in the industry, must be carried out in order to set up an exact energy scheme for the purification process.



Proposed system design

The removal of organic matter from process water is carried out by an UASB reactor (Upflow Anaerobic Sludge Blanket Reactor), figur 1. This reactor system is a closed system with the active microbial biomass immobilised on granula. The microbial granules will be detained in the reactor system also at high flow rates, due to their high density.

Former experiments on anaerobic degradation of organic matter in process water from fish processing, have shown a great potential of the described treatment system.

The removal of nitrogen through a nitrification/denitrification process will be carried out as a separate nitrification unit (figure 1), followed by recirculation of the nitrified water into the anaerobic UASB-reactor. While denitrification uses a lot more energy than metanogenesis, the activity in the sludge blanket will be separated in a denitrification and a metanogenic zone, with denitrification taking place in the bottom of the sludge blanket and metanogenic activity in the rest of the sludge blanket.

Alternatively, the denitrification can be carried out in a separate reactor, if it turns out to be the most favourable solution. This could be the fact is alternative carbon sources is available from waste products produced within the industry.

The reactor volume based on treatment of 60 m^3 per day can be calculated to approximately 15 m^3.

Environmental effect of the concept

The improvement of the process will be an integrated part of the supply of energy and water to the industry.

The purification of the water requires less energy than an equivalent aerobe process, as the oxygen demand for the degradation of organic matter is eliminated.

The project has the following environmental and resource recovering effects:

- Reuse of 50-75 % of the process water, thereby reducing the running costs for tap water.

- Process water from fish processing typically contains a chemical oxygen demand of 20 kg COD/m^3. If the oxygen demand has to be reduced to about 0.1 kg COD/m^3, an aerobic process requires an amount of oxygen of about 19.9 kg $0_2/m^3$ process water.

Today, this oxygen consumption takes place in the bay of Agadir Sea. Implementation of the described system will reduce this oxygen consumption with 95-98 %.

- Reduction in the discharge of nitrogen and phosphorus of 90 and 30-90 %, respectively, depending on the system design.

If the oxygen amount is met a corresponding release of CO_2 of 1.6 tons per day will be avoided with the installation of this treatment system.

Project plan

Phase 1

This phase will include a detailed examination of the flow of water and materials through the different processes in the industry. Detailed chemical analysis will be carried out at different stages of the process. Determination of the water quality requirement will also be carried our at different stages of the process. The investigation shall be carried out in close co-operation with the Institute Agronomique et Veterinaire Hassan II (IAVH).

Phase 2

Elaboration of detailed plans, the demonstration plan including system design plans for use of energy (CH_4) and the produced heat and electricity as well as reuse of water. The system design should be based on tests carried out in Europe and at IAVH.

Phase 3

Implementation of a full scale demonstration unit at the selected fish conserving industry.

Replicable projects

The espadon fish conserves industry is in many respects typical among the 64 conserving plants that is found in Morocco. Concentrations on these plants around the city of Safi (50 %) Essaouira (11 %) and Agadir (34 %) make a good basis for constructing replicable projects once the technology has been succesful demonstrated. Many of these industries are located fairly close to one another and the pollution from the waste water is quite often ending in the same places. It is also clear that in the area of Agadir that is a tourist resort makes it is very important to avoid any possibility of spoiling the recreative areas.

A demonstration project should therefore create a success story in a strategic selected industry and combining the story with the possibility through national and international channels to make available money that can be used in combination with grants and loans to diminish the pollution from the industry combining it with possibilities of reuse of water and energy production. Both through the Ministry of Agriculture, the Ministry of Industy the environmental authorities as well as through the Institut Agronomique Veterinaire Hassan II, a lot of possibilities exist of disseminating the results from this project. This can go through the Union of Fish Industries as well as specific seminars about the results. An information and dissemination package is therefore included in the project proposal.

ECONOMY	Total installation
- Planning services - Construction works - UASB reactor system - Definitrication - Gas motors (100 KW) - Piping/el system - Heating - Control system	USD 25.000 USD 30.000 USD 120.000 USD 20.000 USD 90.000 USD 30.000 USD 20.000 USD 50.000 USD 358.000
Management, Training & Laboratory Tests	
- Laboratory test - Detailed design - Travel - Training in europe - Management programme	USD 8.000 USD 30.000 USD 20.000 USD 55.000 USD 45.000 USD 158.000
Total	USD 543.000

Suggested form of financing	
National 50 % of 385.000 = USD	USD 192.500
National 50 % of lab.test and detailed design	USD 19.000
International	USD 331.500
Total	USD 543.000

PROJECT 3

The amount of household waste from the major cities in Morocco has been estimated. The table below shows the data from various cities. In general the percentage collected varies between 70 - 85. A daily total of 3.800 tonnes of household waste is deposited in the major landfills around the cities. All together household waste amounts to around 8.000 tonnes per day from the cities in Morocco. The household waste is characterized by having a relatively high humidity content, in general approximately 70 %. This is due to the fact that the kitchens in Morocco normally use substantial amounts of vegetables. The high humidity content naturally makes it more expensive to incinerate the waste. So far no incineration plants have been built in Morocco. Three cities, namely Marrakesh, Rabat and Meknes produce compost from household waste. The compost is of a relatively poor quality and is sold to the farmers at a price of 40 DH per tonnes. It is uncertain whether a market for this type of compost exists unless the quality of the compost is improved. The farmers complain of large amounts of plastic waste in the compost which consequently pollutes the fields. A new compost unit is under construction in Agadir.

Table

Household waste	Population	Percent collected	Production kg/h/d	t/d
Casablanca/Mohammedia	3.900.000	80	0.6	1900
Rabat/Salé	815.000	80	0.6	400
Fes	725.000	70	0.6	320
Meknes	500.000	80	0.6	250
Oujda	380.000	80	0.6	200
Marrakech	640.000	85	0.6	350
Tanger	410.000	85	0.6	230
Tetouan	290.000	75	0.6	150
Total from these cities				3800

The purpose of the described project is to construct a biogas unit that is using selected municipal waste. The benefits of this unit would be

1. Production of fertilizer to the neighbouring farms and greenhouses.

2. Production of biogas to be used for electricity production.

The amount of fertilizer to be produced will be 80 tonnes per day or 28,800 tonnes per year. This will give an income of USD 151,600 per year.

The production of biogas will be based on the following input.

Type	Amount (t/day)	Dry matter (t/day)	Volatile solids (t/day)
Segregated household waste	30	9	7.5
Expired food	5	2.1	2
Segregated hotel/restaurant waste	10	4	3.5
Vegetable market waste	10	4	3
Slaughterhouse waste *)	18	4	3.6
Chicken waste	5	3	0.8
Bleaching soil	2	1.95	0.7
Total	80	19.45	21.1

Table Waste composition of the demonstration plant, *) including blood waste.

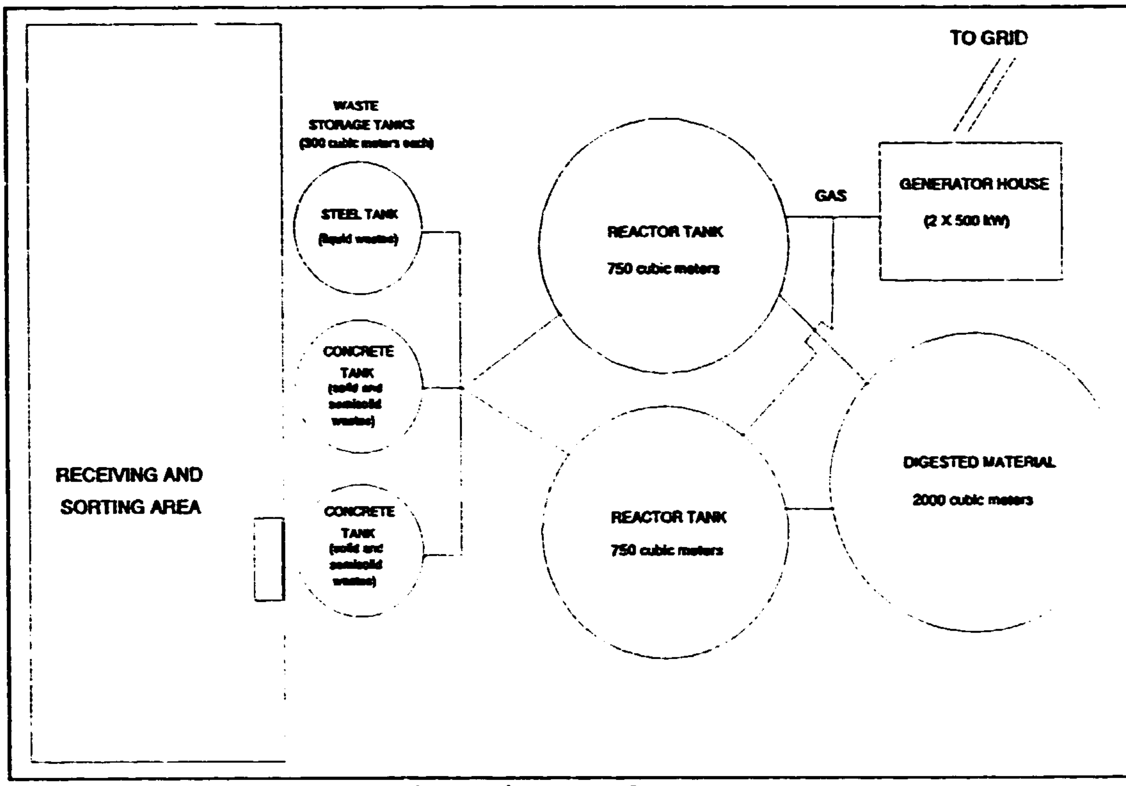
The expected content of organic matter (volatile solids, VS) in the waste is 71% of total solids on average, making up about 21 tonnes of VS/day. Depending on the quality and composition of the waste, the average biogas production will be at least 300-450 m^3 CH_4 per tonne of VS.

The electricity production will be:

Biogas generated	12,000 m^3/day
CH_4 generated	8,000 m^3/day
Electricity output	26,400 kWh/day
Internal use	2,400 kWh/day
Electricity for sale	24,000 kWh/day
Income DH	16,800 DH/day
In USD per year	636.000
Generation equivalent	1 MW

Proposed system design

The figure below shows the overall plan of the demonstration biogas plant. The main components are the receiving area, the 3 pre-storage tanks for different waste sources, the reactor tanks, the storage tank for digested material (fertilizer) and the electricity generating unit, which is shared with the landfill gas facility.



Plan of the demonstration biogas plant.

Budget Estimate in US USD

BIOGAS PLANT:

2 reactor tanks, 1000 m^3 = 2000m^3 :	700,000
2 mixer systems:	175,000
Installation:	25,000
Pipes, fittings and valves:	50,000
2 heating systems:	75,000
Subtotal:	1025,000
2 storage tanks with lids, 300 m^3	40,000
2 mixer systems:	30,000
Maceration systems:	30,000
Pipes and fittings:	10,000
Subtotal:	110,000
1 steel storage tank 300 m^3:	20,000
1 mixer system:	15,000
Pipes and fittings:	10,000
Installation:	10,000
Subtotal:	50,000
1 storage tank to digested material, 2500 m^3:	220,000
2 mixer systems:	25,000
1 lid for storage tank:	10,000
1 gas system:	15,000
Pipes and fittings:	15,000
Installation:	15,000
Subtotal:	300,000

Pumps:	40,000
Valves:	20,000
Pipes, valves and fittings:	20,000
Installation:	30,000
Unforeseen expenses:	50,000
Subtotal:	160,000

Gas system:

Gas blower:	25,000
Valves + measurement equipment:	20,000
Flare + gas:	35,000
Pipes and installation:	50,000
Subtotal:	130,000

Heating system:

Pumps:	10,000
Pipes, fittings and valves:	20,000
Sensors and measurement equipment:	20,000
Installation:	30,000
Subtotal:	80,000

Laboratory equipment:	50,000
Monitoring and regulation system:	75,000
Drawings,projecting and conducting:	150,000
Subtotal:	275,000

Total, biogas plant:	2,135,000

ENERGY GENERATION SYSTEM

2 Gas engines 2x500 kW = 1 MW:	700,000
Subtotal:	700,000
Total, energy generation system:	700,000

TRAINING, MANAGEMENT AND EDUCATION IN US USD

System design, construction management:	100,000
Project management, 2-year program:	280,000
Education and training of plant manager and one technician in a biogas plant approximately 6 months:	120,000
Subtotal:	500,000
Grand total:	3,335,000

Suggested form of financing:

National 50% of USD 3,335 mio = 1,667 mio
International 50% of USD 3,335 mio = 1,667 mio

PROJECT 4

Training, demonstration and education

As the environment awareness is increasing in Morocco it seems important not only as recommended in the report to strengthen the organizational structure, but also to strengthen the facilities for education, training and demonstration. Today the only major university institute that carries out work in this field is Institut Agronomique et Veterinaire Hassan II, and it is recommended in the present project proposal that these facilities are strengthened.

In the years to come waste from the agro industry and possibilities for biogas in the rural districts, waste water from the sewage systems as well as municipal waste mean that Morocco will have to make major investments in order to cope with the problems that will occur in these sectors. In order to handle this in an optimum manner it is necessary for Morocco to have its own resources of trained staff that can advise the Moroccan authorities and the industry.

For the industry sector it is of course of major importance to cope with both the waste form 13 major sugar plants, the olive industry as well as the fish processing industry. Solutions can naturally be found using foreign consultants but given the fairly strong university set-up in Morocco it would be a pity not to give due consideration to the possibilites of using Morocco's own expertice. The following programme includes a short description of the various elements that can be included in an institutional strenghtening in this area. Since qualified people exist at the Institut Agronomique et Veterinaire Hassan II, it has been recommended that the institutional strengthening takes place here.

The operation of modern biogas plants (anaerobic digesters) require various chemical and physical analyses of the feed material, the reactor contents and the products biogas and fertilizer to ensure an efficient and well functioning process. Some of the chemical and physical parameters that is necessary to measure are:

Chemical and Physical Parameters to be measured:

1. **Biogas composition**

The biogas digesters will have, installed as on-line measurement, flow meters for measurement of gas production. However, gas composition can also be measured periodically by various other methods, gas chromatography, volumetric subtraction, *etc.* Gas composition should be measured daily and gas production should be monitored continuously.

2. **Volatile Fatty Acids (VFA)**

VFA (acetic acid, propionic acid, isobutyric and butyric acid, isovaleric and valeric acid, hexanoic and heptanoic acid) are important intermediates produced during the microbiological degradation of organic matter during the biogas process. VFA are also generally regarded as the most important parameter to be measured for steering and regulation the biogas process. VFA should be measured daily. No methods currently exist for on-line measurement of VFA, but various methods (titration methods, gas chromatography etc.) of varying complexity and accuracy suitable for use at biogas plants are available.

3. **Alkalinity and *p*H**

Alkalinity is an important parameter to measure for control of the buffer capacity of the reactor process, and so for *pH* control, and for control of scaling in the plant. Alkalinity should be measured at least weekly and more often if it is found that *pH* control is necessary during the operation of the plant. The *pH* of the biogas process normally runs best within a narrowly defined range, between *pH* 6.5 to 8.5 and especially the methanogenic bacteria are sensitive to *pH*. The reactor *pH* should be measured daily: *pH* measurement is a very standard technique and many methods suitable for at-plant use are available.

4. **Total Solids/Volatile Solids Removal**

These two parameters reflect the efficiency of the biogas process in converting the solid dissolved waste into biogas. It is not a critical, daily steering parameter but is important in the overall evaluation of the process performance. Solids removal should be measure weekly.

5. **Nitrogen and NH_3 content**

Nitrogenous substances are important nutrients in the biogas process and a minimum ratio between nitrogen/NH_3 and total organic carbon input should be maintained for good process efficiency. If N is lacking in the reactor extra high-N wastes, such as slaughter house wastes, can be added; however, excessive concentrations are inhibitory. Additionally, it is of great interest to know the nitrogen/NH_3 concentration in the effluent produced at the plant for its evaluation as a fertilizer. Various wet chemical methods are available for biogas plant monitoring which can be employed on-site.

6. **Salinity**

Salinity is most important, not with respect to the biogas process, but in relation to the use of the digested material as a soil conditioner and fertilizer. Soil salination is a common problem in heavily utilized agricultural land and the salinity of any conditioner/fertilizer applied should be considered. This has never been shown to be a problem with anaerobically digested material but occasional monitoring is prudent. Salinity, measured as total dissolved solids or conductivity, is a very standard technique measurable by various methods. Salinity should be monitored at least weekly.

Elements of a research task training programme

In the following is various tasks described and how each one can be included in a research/demonstration programme in anaerobic digestion at university level with specific relevance to "difficult" waste types as for example the case with waste from the olive industry.

T1: Waste water characterization

Flowrate measurements and samples for lab analysis will be taken over a one-year-period in order to assess the variations in their quantitative and qualitative characteristics. Although some such data exist, the data are insufficiently characterized for the purposes of the proposed research. This is necessary information for (a) defining a typical "average" waste water (tasks 2 and 3), and (b) performing the optimal treatment system/protocol determination (task 4).

T2: Anaerobic biodegradability of individual sources

Appropriate inocculating cultures will be developed and the kinetics of biodegradation of individual source waste waters will be assessed. The kinetic information will be necessary for development of the co-digestion criteria.

T3: Anaerobic biodegradability of mixed sources

The kinetics of mixed waste water anaerobic biodegradation will be determined and co-digestability criteria will be assesed. This is necessary information for the optimal treatment system protocol determination (task 4).

T4: Appropriate feeding pattern(s) and pretreatment/mixing tanks

A software optimization package for treatment system/protocol assessment will be developed. This task is based on the information about the waste sources (Task 1) and the co-digestion criteria developed in task 3. This is necessary in order to proceed with digester configuration testing (task 5) and pilot-scale demonstrations (Task 8).

T5: Digester configurations for effective co-digestion

The treatment protocol obtained in task 4 will be imposed on three different digester types in order to decide on the most appropriate type for co-digestion. The possible need for waste water pretreatment and the availability of mixing tanks will be assessed. The information generated here will be important for the pilot-plant design (Task 8) and for assessing the by-product value (Task 6).

T6: By-products value assessment

The energy value of the produced biogas during co-digestion and the possible uses for the generated mixed liquor will be assessed. This task is necessary for arriving at conclusions regarding the overall economies of co-digestion. Furthermore this work will have implications on the pilot-plant designs (Task 8).

T7: Flexible mechanical parts and control systems

Flexible mechanical parts design for the three digester types will be developed in order to provide the maximum possible flexibility of operation. Although one reactor type will always be selected in each case, this may vary from one case to another. Furthermore, this work will suggest the modifications needed to existing plants. Flexible design can be very important in view of the seasonal nature of the feed characteristics. Complete data acquisition and control systems will be developed for the co-digestion process. The generated information will be used for designing and constructing the pilot-scale operations.

T8: Pilot-scale studies

A pilot-scale system will be built in Morocco. The first will be focussed on co-digesting waste water sources from different agri-food industry operations e.g. olive-mills and dairies. The information generated in tasks 4 (optimal feeding protocol), 5 (optimal reactor type) and 7 (flexible mechanical and control system design) will help in designing and constructing the best pilot-scale operations possible. Those will run for a whole year in order to assess and demonstrate their performance.

Project Methodology

The development of an optimal co-digestion process comprises the following main research tasks:

- kinetics of biodegradation
- optimal protocol/process assessment
- lab-scale bioreactor design
- byproduct value assessment
- flexible bioreactor design
- prototype experiments

Kinetics of biodegradation

The relationship between the waste composition (carbohydrates, lipids, proteins etc.) as well as the organic fraction (and other waste characteristics) of individual sources and the digestibility of mixed source waste waters will be investigated. This will be done by determining through draw and fill experiments. The ability of an anaerobic culture to adapt to such changes in the feed media will be established. At first, these questions will be addressed both from a microbiological and a process point of view. Appropriate modelling (transient material balances with the complex waste composition taken into account) for the co-digestion processes will be developed for use with the determination of the optimal reactor design and feeding strategies.

Optimal protocol/process assessment

Once the co-digestion technology related questions have been answered, the next step (optimization) represents a problem of multiperiod optimization with continuous and integer variables. A software package will be developed capable to decide which waste sources and when should be treated, as well as the number and location of treatment sites.

Lab-scale bioreactor tests

Different continuous reactor types (CSTR, UASB and ABR) will be evaluated from the co-digestion point of view by imposing the optimal treatment protocol and assessing the treatment performance through on-line and off-line measurements.

Byproduct value assessment

The digester effluents will be considered for exploitation as fertilizer (the solid fraction) and water reuse. Deep filtration, reverse osmosi and ion-exchange will be examined as alternatives. The generated biogas will be assessed. The economic value of the generated byproducts will be determined.

Flexible bioreactor design

Flexible and robust bioreactors, capable of handling parameter variations will be designed. This will involve moving mechanical parts and control systems and operating strategy/determinations.

Prototype experiments

Two prototypes will be appropriately modelled and optimised. The prototype in Greece will be for waste from various alternate agricultural sources, whereas that in Denmark for waste of the same food processing industry will be processing different raw materials around the year.

Assessment of technical risk

The proposed research will definitely lead to new knowledge of great technological value and, in our opinion does not have any significant risks. It is believed that it will be possible to have a system co-treating e.g. olive-mill waste, dairy waste and cannery waste sequentially without any problems. What is not known are the appropriate criteria for selecting what to co-digest and the appropriate rector design and operation. Furthermore, the economic ramifications of collection and treatment configurations need to be assessed.

Even though the theoretical basis of the proposed project is well documented, the experimental (pilot plant) and optimization stage contain the risk of poor compatibility (measured as efficiency between the different quality characteristics of the waste waters involved as well as their synchronisation (quantity) in order to have substrate throughout the year.

Equipment needed for a demonstration laboratory at Institut Agronomique et Veterinaire Hassan II

8 reactors 4 l each including pump and circulation	USD 40.000
2 reactors 9 l each including steering system	USD 15.000
1 gas chromatograph including computer system	USD 32.000
Various analytic equipment, glass etc.	USD 42.000
UASB reactor 700 l } 4 tanks at 2.5 m^3 } Piping } Cutter } Local steering }	USD 255.000
Global monotoring system	USD 25.000
Total equipment	USD 409.000

Training programme abroad	
2 students Ph.D	USD 80.000
Local training	USD 40.000
Foreign assistance 8 man months	USD 120.000
Total	USD 240.000

The project is proposed financed by international donors