Project no. COOP-CT-2003-507997

Project title

Development of an Autonomous Low-Temperature Solar Rankine Cycle System for Reverse Osmosis Desalination

Instrument
Horizontal Research Activities Involving SMEs
Cooperative research

Thematic Priority
Sustainable Energy Systems

Final activity report

Period covered: from 1/7/2004 to 30/6/2006 Date of preparation: 30/8/2006

Start date of project: 1/7/2004 Duration: 24 months

Project coordinator name: Em. Prof. Spyros Kyritsis
Project coordinator organisation name: Agricultural University of Athens

1. Project execution

1.1 Project objectives

The main objective of the present action is the development, installation testing and performance evaluation of an innovative stand-alone, **solar desalination system**, generating mechanical work for RO desalination through a low temperature organic Rankine cycle. Specific objectives are: The development and standardisation of the innovative desalination system; the optimisation of the thermal process and system size and components in order to achieve a cost effective and flexible technology with high adaptability to the desalination market's needs; extrapolating optimisation of the system design to a number of sites; the achievement of competitive fresh water price in comparison to other solar desalination technologies; the establishment of a high complementarity industrial consortium that guarantees the exploitation of the results after the programme end; the access of the involved SMEs to a new market; the definition of the range of the market to which the proposed technology aims at, and finally; the development of a competitive product.

*Specific **technical objectives** of the project are the following:*

Objectives	***Milestones and expected results***
• The assessment of solar potential, other thermal sources potential and fresh water demand in various geographical areas • Cross evaluation of RES availability and water shortage (in quality and quantity) in order to establish areas of market potential • Processing of collected data	• Identification of possible test sites for the prototype system installation, *at month 5* • Overview on regions where decentralised fresh water supply from desalination is a possible solution, *at month 5*
• The assessment of water storage possibilities • The technical and socio-economic evaluation of technology options • The support of design choices regarding water storage	• Completion of needs and technology pre-study, *at month 5* • Communication of shortlist to water storage designing options, *at month 5*
• The optimum system design, including water storage option	• Design tool for system optimisation, *at month 9*
• Selection, manufacturing and procurement of the system' s components	• Market survey on market available system's components, *at month 13* • Manufacturing of system's components, *at month 13*
• Installation, commissioning and operation of the pilot plant	• Installation of the prototype plant and operation, *at month 15* • Results from prototype system operation, *at month 18*
• The evaluation of system performance, the economic assessment and definition of the fresh water cost (€/m^3)	• Identification of the technical and economical feasibility of the system, *at month 24*
• The definition of commercial products of the developed technology and spin-off options and formulates a road-map towards market	• Suitable market sectors for the developed desalination technology are identified, *at month 23* • Suitable market sectors for spin-off options are

penetration.	identified, *at month 24* • A road-map for penetration in these market sectors is formulated, *at month 24*
• Dissemination and publication of the results, training of staff and awareness-raising amongst solar collectors manufacturers in Central Europe	• Final assessment of the work in terms of work programme goals achieved, *at month 24* • The realisation of dissemination programme, *at month 24*

Throughout the project duration all the above objectives were met. The key factor to mitigate the objectives was the design, assembly, operation and monitoring of the prototype system.

1.2 Contractors involved

List of Participants

Partic. Role*	**Partic. no.**	**Participant name**	**Participant short name**	**Country**	**Date enter project****	**Date exit project****
CO	1	Agricultural University of Athens	AUA	GR	1	24
CR	2	Technical University-Munich	TUM	DE	1	24
CR	3	Universidad de Las Palmas de Gran Canaria	ULPGC	ES	1	24
CR	4	Hellas Energy K. Bouzianas D. Moschovitis & Co	HEN	GR	1	24
CR	5	Thermomax Ltd.	Thermomax	UK	1	24
CR	6	WIP KG	WIP	DE	1	24
CR	7	Electrica Centro Ltd	ELEC	ES	1	24
CR	8	Water Ice Systems S.L	WASY	ES	1	24

*CO = Coordinator
CR = Contractor

1.3 Methodologies and approaches employed-Achievements of the project to the state of the art

The research concerned the development, design, assembly and installation, testing and monitoring and performance evaluation of a Low Temperature SORC system for sea water desalination. The prototype system consists of the following sub-systems and components (Fig.1):

1) High efficiency vacuum tube solar collectors' array, 100 kW
2) Circulator
3) Pre-heater (35 kW) and evaporator (73 kW)
4) Condenser, 100 kW
5) Expander, 2 kW

6) HFC-134a feed pump
7) RO unit, 0.3 m^3/h
8) Fresh water reservoir
9) RO energy recovery system

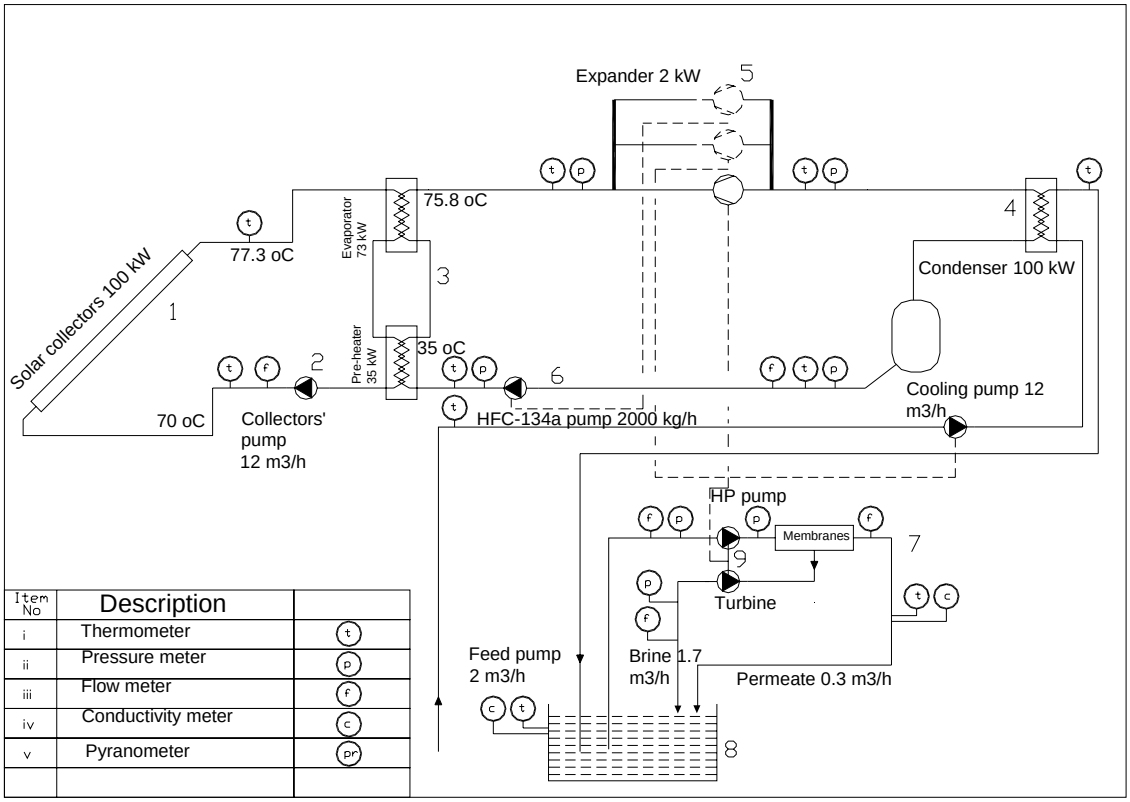

Figure 1. Schematic diagram of the prototype system

The system operation is briefly described below:

Thermal energy produced by the solar array (1) preheats and evaporates the refrigerant (HFC-134a) in the preheater and evaporator surfaces (3). The water temperature at collectors' inlet is 70 ^oC and the outlet temperature 77.3 ^oC. The super-heated vapour is driven to the expander (5) where the generated mechanical power drives the HP pump of the RO unit. The vapour at the expander's outlet is driven to the condenser (4). The sub-cooled liquid at the condenser outlet is then pressurised by the HFC-134a feed pump (6). An energy recovery system is coupled to the RO unit thus declining the specific energy consumption to 2-3 kWh/m^3. The energy recovery system consists of two axial pistons pumps, one running reversely as turbine (APP models, manufactured by Danfoss).

Towards the state–of-the art, the following aspects of **innovations** are pointed out:

- Low temperature thermal sources can be exploited efficiently for fresh water production.
- The solar energy is used indirectly and does not heat seawater (as in sea water distillation); mechanical power is generated from organic fluid (HFC-134a) expansion through a Rankine thermodynamic cycle and drives the RO unit.

- The components of the system (which have so far been developed independently) are tuned each other so that to achieved higher efficiency and consequently higher fresh water production rates.
- RO desalination plants are energized by electricity. In case the energy is produced by RES, PV or wind generators are used. The proposed system uses solely mechanical power generated by heat.
- Direct efficiency gain is achieved through no transformation of mechanical to electric power. In small scale motors the transformation efficiency is very low.
- The general RE Desalinisation design eliminates the storage of energy (intermediate product), when reservoir of water (final product) is used.
- The energy recovery system of the RO unit is composed by axial type piston pumps (APP models manufactured by Danfoss) co-axial connected making direct use of the generated shaft power of the expander.

Figures 2, 3 illustrate the rear and front view respectively of the Rankine engine. Figure 4 gives a general overview of the installation. In figure 2, the heat exchangers of the engines can be seen. In figure 3, the scroll type expander and the energy recovery system of the RO desalination unit are indicated, while in figure 4 the building and the solar collectors' field are illustrated.

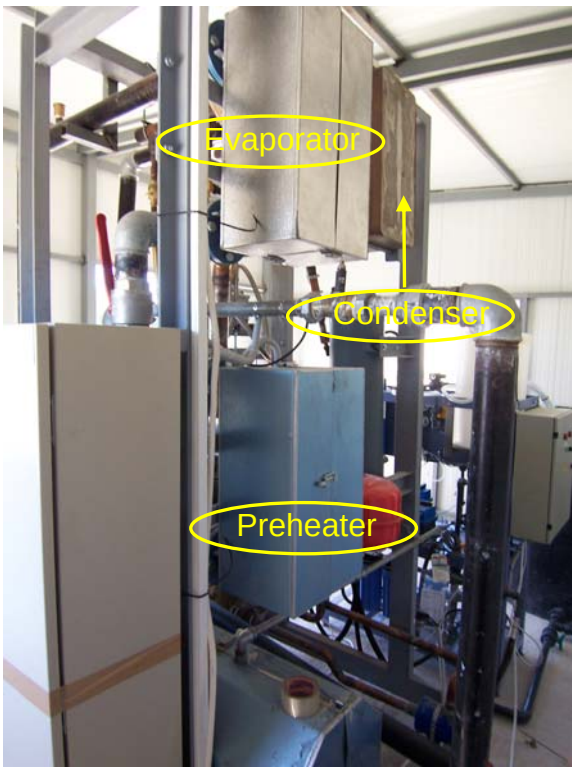

Figure 2: Front view of Rankine engine

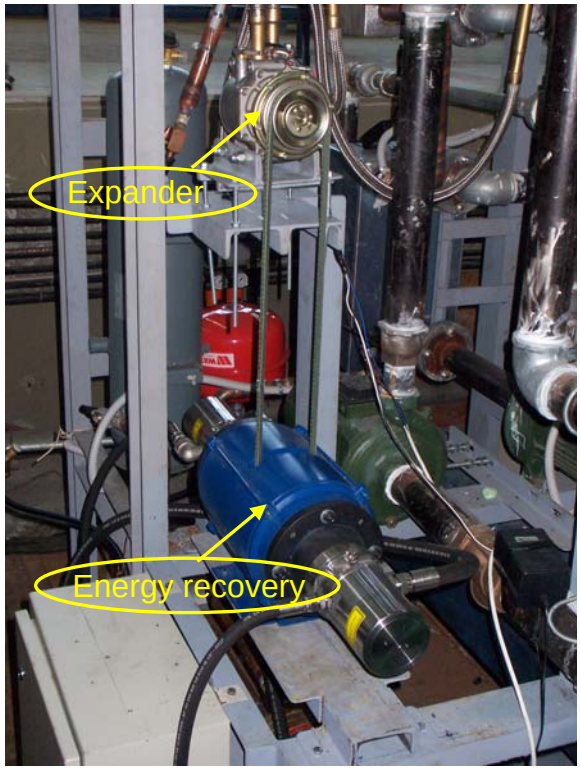

Figure 3: Front view of Rankine engine

Figure 4. General overview of the installation

1.4 Work performed and end results

The work foreseen was divided into 8 Work Packages including management, technical, training and dissemination activities. More specifically, the work performed and the results achieved are summarised in the following:

Work carried out	**End results**
Overall coordination and management of the project	Efficient management of the project
Investigation of solar and other thermal sources potential and fresh water demand	Data base for possible applications of the developed technology
Selection of the installation site	Formulation of criteria for site selection. Selection of the site
Identification of possible sites for potential installation of the developed technology	3 case studies in different geographical areas
Assessment of water storage possibilities, technical and socio-economic evaluation of technology options and the support of design choices regarding water storage	Selection of the suitable water storage in terms of assuring uninterruptible water supply at high water quality standards
Communication of shortlist to water storage designing options	Extraction of a standard procedure to design water storage correctly
Design tool for system optimisation	Design of the prototype system
Market survey on market available system's components	Selection of market available system components
Manufacturing of system's components	Manufacturing of solar collectors and other parts of the prototype system
Procurement of system components not produced by the partners involved	Purchase of system components
Infrastructure works in the installation	Construction of concrete bases and

site	metallic supporting frames of solar collectors, water and electricity supply, building construction for equipment housing, piping, wiring etc.
Assembly of the system components	The prototype system completely synthesised
Start-up of the system and laboratory tests realisation (A-tests)	Laboratory operation, measuring and recording critical parameters
Start-up of the system and in site tests realisation (B-tests)	In site operation, measuring and recording critical parameters
System monitoring and data acquisition	Experimental optimisation and regulation of the system
Processing of experimental data	Evaluation of system performance
Economic evaluation of the system	Identification of fresh water cost
Identification of environmental impacts	Assessment of environmental impacts
Identification of socio-economic impacts	Assessment of socio-economic impacts
Development of market penetration strategy	Formulation of roadmap towards market penetration of the new product
Training activities	Training of engineers and technician on the developed technology
Dissemination activities	• Printing of dissemination material (CD and leaflet) • Participation in international events (conferences, seminars) • Writing of paper published in international journals • Organisation of two workshops

2. Dissemination and use

Plan for using and disseminating the knowledge

In the following table the exploitation plan of the generated knowledge is presented.

Exploitation of knowledge table

Exploitable Knowledge (description)	**Exploitable product(s) or measure(s)**	**Sector(s)** of application	Timetable for commercial use	Patents or other IPR protection	**Owner** & Other Partner(s) involved
On assessment of renewable potential and fresh water demand	Data base	Desalination, renewables	-	-	**All SMEs and RTD performers**
On behaviour of scroll type compressor as expander	Scroll performance in reverse operation	Turbomachines	-	-	**HEN**
On minimisation of energy consumption of	Energy recovery system	Desalination	-	-	-

Exploitable Knowledge (description)	**Exploitable product(s) or measure(s)**	**Sector(s)** of application	Timetable for commercial use	Patents or other IPR protection	**Owner** & Other Partner(s) involved
the RO unit					
On the integrated developed system	The integrated developed system	Desalination	2007	A patent on the developed system	**All SMEs**
On control logic of the system	Control software	Power generation	-	-	**HEN (owner)**
Simulation-optimisation methodology	Simulation-optimisation software	Thermal processing, collectors industry, desalination	-	-	**AUA and TUM**

Dissemination of knowledge table

Planned/actual Dates	**Type**	**Type of audience**	**Countries addressed**	**Size of audience**	**Partner responsible /involved**
14-15/06/2004	INCO-MED Water Conference 2004 (Amman, Jordan)	Research-industry-local authorities (water desalination)	MEDA countries	50+	Oral presentation, AUA
20-23/06/2004	Eurosun 2004 Conference (Freiburg, Germany)	Research-Industry (solar thermal sector)	International	80+	Oral presentation, AUA
15-19/03/2005	ISH Solar Exhibition 2005 (Frankfurt, Germany)	Industry (solar thermal sector)		100+	Thermomax Ltd
22-25/05/2005	EuroMed2005 Conference (Santa Margherita-Portofino-La Spezia, Italy)	Research-Industry (water desalination)	International	100+	Oral presentation, AUA
21-22/06/2005	Estec2005 (Freiburg, Germany)	Conference	International	50	Oral presentation, Thermomax Ltd
23-25/06/2005	Intersolar 2005 (Freiburg, Germany)	Industry (solar thermal sector)	International	100+	Thermomax Ltd
25-26/09/2005	ADU-RES Workshop (Tunisia)	Research-local authorities	MEDA countries	100+	WIP-AUA
13 – 14/10/2005	SIMS 2005 (Trondheim, Norway)	Model builders, simulator personnel, scientists, engineers, vendors, etc	International	100+	Oral presentation, TUM
05 – 07/11/2005	2005 WSEAS International Conference on Environment,	Research	International	100+	Poster, AUA

Planned/actual Dates	Type	Type of audience	Countries addressed	Size of audience	Partner responsible /involved
	Ecosystems and Development (Venice, Italy)				
21 – 25/05/2006	EuroMed 2006 Desalination Strategies in South Mediterranean Countries (Montpellier, France)	Research-Industry (water desalination)	International	100+	Oral presentation, AUA
12 – 14/07/2006	ECOS 2006 (Crete, Greece)	Research - Industry	International	100+	Oral presentation, TUM
2005	Publication in Desalination journal	Research-higher education			AUA
16/06/2006	Workshop	Research-Industry (solar collectors, desalination)	Greece	50	Organization AUA, ULPGC - Oral presentation AUA, TUM, ULPGC, WIP
October 2004	Project web site				AUA
March 2006	leaflet			500	AUA
March 2006	CD			100	AUA

3. Contact details

Dr. Dimitris Manolakos
Agricultural University of Athens
Dept. of Agricultural Engineering
Laboratory of Farm Structures
75, Iera odos street 11855, Athens
Greece
Web: www.rosolar.aua.gr