Bulgarian Chemical Communications, Volume 48, Special Issue E (pp. 96 - 101) 2016

Specialized measuring system for analysing thermal fields in hybrid systems

S. N. Lishev[1], R. K. Popov[2*], A. G. Georgiev[3,4]

[1]*Department of Optoelectronics and Laser Engineering, Technical University of Sofia - Plovdiv Branch, 25 Tsanko Diustabanov St., 4000 Plovdiv, Bulgaria*

[2] *Department of Electronics, Communications and Information Technologies, Plovdiv University "Paisii Hilendarski", 24 Tzar Assen St., 4000 Plovdiv, Bulgaria*

[3]*Dept. of Mechanics, Technical University of Sofia, Plovdiv Branch, 25 Tsanko Diustabanov St, 4000 Plovdiv, Bulgaria*

[4]*European Polytechnic University, Dept. of "Green Energy", 23 Kiril and Metodiy str., 2300 Pernik, Bulgaria*

The analysis of thermal fields requires the collection and processing of information about the temperature in many points in the zone that is under investigation. A specialized autonomous measurement system, developed by Bulgarian scientific team from Plovdiv is presented in the article. It enables long-term recording of temperature data in more than 100 points. The system is designed for analysing thermal fields in Phase change materials storages in hybrid systems. It is also suitable for related applications like chemical and biochemical reactors, and columns, if the temperature is in the range of -20 ° to +125 °C. Data is stored in SD-card and can be transferred via USB interface to the PC by specialized software, where the thermal fields could be visualized.

Keywords: hybrid thermal systems, thermal field measurement, chemical and biochemical reactors

INTRODUCTION

There is a growing use of renewable energy sources to reduce the greenhouse gasses released into the atmosphere. The efficient use of solar and wind energy is among the main tasks in solving the energy problem of humanity. Its disadvantage is the uneven distribution, frequent changes over time and their difficult prediction. This has led to the development of a number of technologies for flexible usage, one of which is energy storage [1].

One of the ways for energy storage is the use of phase change materials (PCM). PCMs are used to balance temporary temperature alternations. They have a number of advantages compared to other heat storage methods - high specific heat capacity, relatively constant temperature during charging/ discharging. However, there are still some problems in the use of materials with change of phase state:

- Phase separation leads to inhomogeneous distribution of the material and thus alter the characteristics of the storage of heat;
- Overcooling leads to a change of phase at a lower temperature, resulting in the release of energy at a lower temperature;

Low thermal conductivity is problematic because it requires more time to reach the desired temperature throughout the material over time, which leads to change in temperature with distance from the heat source [2].

* To whom all correspondence should be sent: rum_pop@yahoo.com

The solving of these problems can be accomplished by better study of their technical characteristics like thermal and hydrodynamic behaviour during operation, which makes possible to improve the structure of the latent heat storages. During the design phase in a particular PCM application tasks numerical modelling and analysis becomes an essential tool [3]. Common approach in modelling is the finite-element analysis. Gong et al. [4] use this method to develop a model in order to simulate cyclic thermal process occurring in shell-and-tube latent heat thermal storage exchanger. Another type of analysis is done by Amin et al. [5] to calculate the phase change effectiveness using the ε-NTU method. Although there are many models developed, there are still many aspects that are not studied completely like heat transfer characteristics inside packed bed and thermal gradients inside the capsules at high temperatures in packed bed thermal storage systems [6]. In order to validate simulation and numerical models more experiments are needed with real thermal systems.

To satisfy this requirement a specific demand exists in measurement systems:

- multiple point measurement;
- long-time autonomous data acquisition;
- adequate accuracy and precision;
- automation of the measurement process etc.

On the market today there are no available such devices. Some portable, battery powered data loggers ensure up to 2-8 measurement channels [7].

Another approach is using PC based data acquisition systems [8]. In this case [9] a 1-Wire to

USB gateway unit performs interface connection to the sensor network. Several hours of autonomous operation is provided by the laptop battery. The number of the measurement and control points is more than 100. Instead of temperature sensors, humidity sensors, memories and output control devices can be connected to the 1-Wire network.

In this article the development of a specialized, portable, multichannel system for study of thermal fields in hybrid thermal installations with latent heat accumulators is proposed by the scientific team from Plovdiv. The system can provide stand-alone operation for at least a month.

TEST SYSTEM OVERVIEW

Experimental hybrid installation for heating, ventilation and air conditioning (HVAC), developed by scientific team from "Technical University of Sofia", Plovdiv Branch is used [10]. Its purpose is to study the system parameters in the process of testing the latent heat accumulator that is charged by solar energy. On Fig.1 is shown the schematic of the system. Three solar collectors with a total area of 5.82 m^2 are used. They are connected to a water tank, which acts as a heat exchanger.

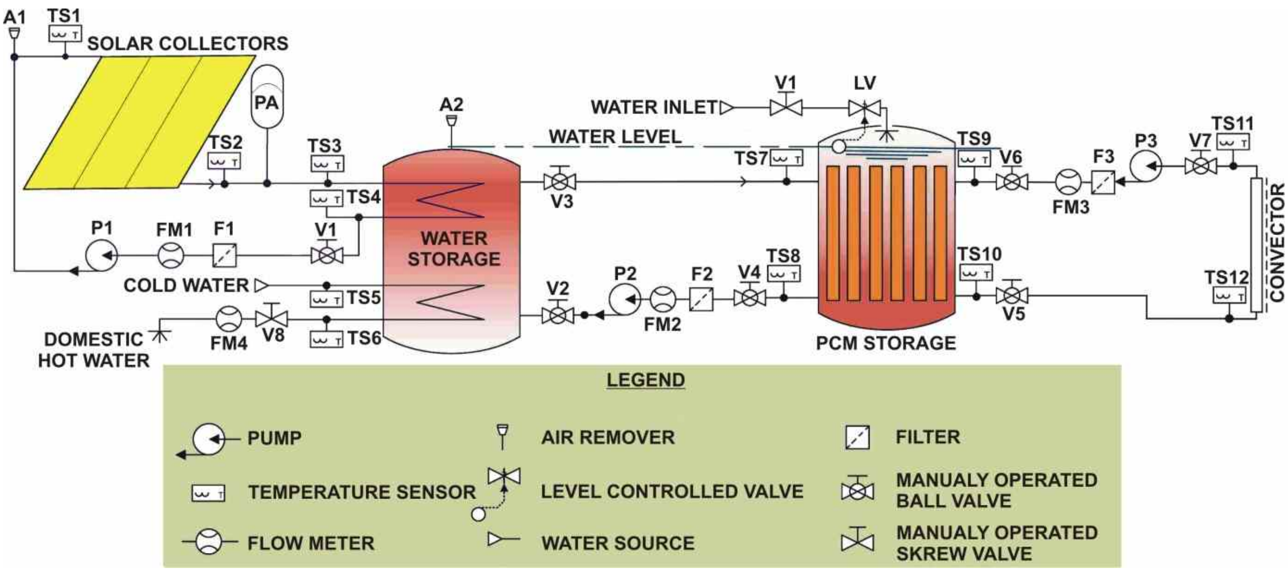

Fig.1. Block scheme of the test system [10]

The solar collectors are divided by a heat exchanger from the rest of the system, thus enabling its use in the winter season, by the use of a liquid having a low freezing point.

The water storage tank is equipped with a heater, which is used in case, that the solar radiation is not sufficient. Through the heat exchanger the hot water passes into the heat storage based on phase change materials (different types of paraffin wax are used). The construction of the heat storage tank is shown in Fig.2.

In the water tank there are 39 containers filled with paraffin wax. The containers are made of stainless steel square pipes with dimensions of 80 x 50 x 1,5 mm. The tank has three inlet pipes, located in the centre of the bottom side and three outlet pipes, situated at the periphery of the top side. The angle between pipes is 120 °.

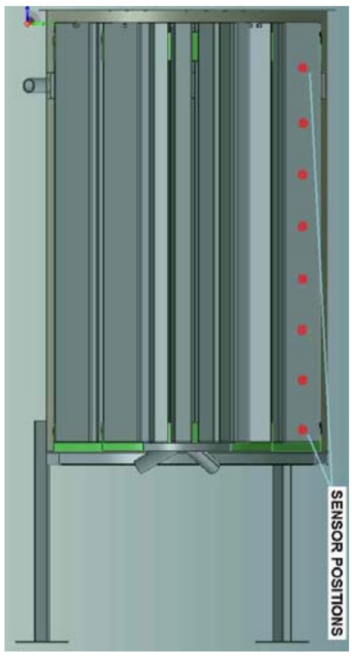

Fig.2. Vertical positioning of sensors

The temperature sensors are placed inside and outside the containers at the shape of 5 vertical lines. The vertical plane of the sensor's positions is shown on Fig.2. The location of the vertical sensor lines in a horizontal plane is shown on Fig.3.

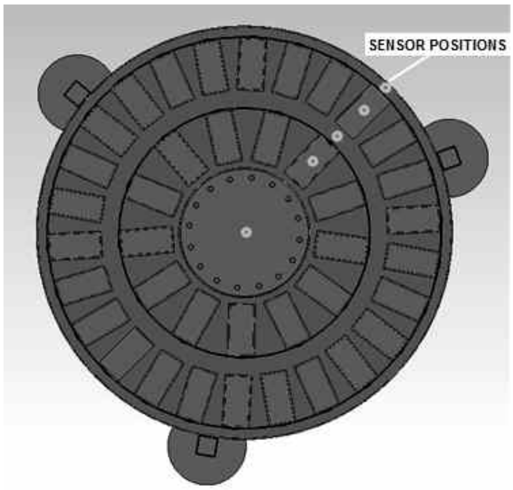

Fig.3. Horizontal positioning of sensors

To study the properties of paraffin wax and thermal behaviour of the heat storage, the temperature has to be measured in multiple points. Using this data an accurate temperature profile of the system may be done. For this purpose it has been developed specialized measurement system that simplifies and automates the measurement of thermal fields in hybrid systems. The unit can be easily adapted for other types of applications.

MEASUREMENT SYSTEM HARDWARE

The measurement system is capable to carry out periodic measurements in up to 128 points by temperature sensors of DS18S20/ DS18B20 type. The sensors have precision of ± 0.5 °C in the range of -20 °C to +125 °C which is adequate for the application.

The measurement system consists of:

– Measurement module;
– Specialized software for visualizing data;
– Temperature sensors DS18S20/DS18B20.

Measuring module was developed using 8-bit PIC18F47J53 microcontroller [11]. The microcontroller is with RISC architecture (Reduced Instruction Set Computer), which has the following key features [12]:

– A small number of instructions;
– Simple instructions are executed in one machine cycle - it makes possible the precise times for real-time tasks in embedded systems;
– A smaller number of transistors compared to the CISC (Complex Instruction Set Computer) architecture, which leads to lower consumption.

One of the main objectives of this development is the low power consumption that provides long-term operation of autonomous battery. The chosen microcontroller meets these requirements with the "nanoWatt XLP" mode, having the following characteristics:

– Deep sleep mode with minimum consumption of 13 nA, real-time clock of 850 nA, inactive processor and other peripheral modules;
– Sleep mode inactive processor and peripheral modules, and active operating memory;
– Idle mode with inactive processor and active peripheral modules.

Different modes allow flexible organization of resources used to achieve low power consumption. The disadvantage of the selected microcontroller is the insufficient amount of RAM and the lack of convenient Flash Memory for storing the system settings. For this purpose external SRAM and EEPROM memory of size respectively 512Kbit and 2Kbit are added, and together with the SD card operates with a common bus interface SPI/I^{2}C. The external RAM is mainly used for:

– Input and output buffers for SD card recording and reading;
– 1-Wire temperature sensors DS18S20/ DS18B20 addresses storage;
– USB to PC transition buffer.

The general scheme of the measurement module is presented on Fig.4. The microcontroller communicates with the temperature sensors network and saves the accumulated data periodically in a SD card. There is a PC to USB interface connection mode. The device is registered as a serial terminal in text mode and can receive commands and send messages. In this mode, the measured temperatures are displayed at the moment. The measurements are carried out periodically, and the time can be set in a range, starting from 5s and up to one week in an interval of 1s. The minimum required time depends on the number of connected sensors. Each sensor has analog-to-digital converter and digital 1-Wire interface [13], formerly known as MicroLAN™. It is designed to perform communication between computer or microcontroller and multiple 1-Wire devices such as sensors, memories etc. via twisted pair cable. This protocol uses only one line for transmitting and receiving and can say that it is a "half-duplex" transmission. There are (in our case) 40 temperature sensors, arranged in 5 rows at 120 mm distance. Taking into account the number of sensors and the physical characteristics of transmission media, the system can be considered as a transmission line. In such cases, the decision is to use termination resistors at both ends, but in this case it is not applicable. So an alternative measures are taken to increase the length of the rising and falling edge, which limits upper bandwidth of the signal. For this purpose a specialized interface chip (DS2482-100) is used. It communicates with the sensor network and connects to the microcontroller through a digital I^2C interface.

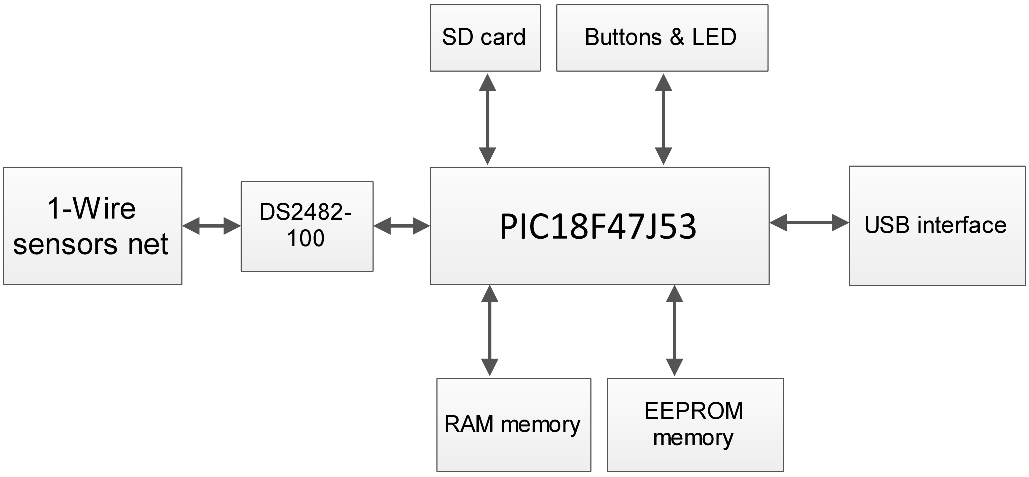

Fig.4. Block scheme of the measurement module

Fig.5 shows the view of the prototype board, developed in the Technical University of Sofia, Plovdiv Branch.

Fig.5. The prototype of the measurement module

Measurement module is powered by two AA size batteries that allow long term autonomous operation – up to 1 month. That is obtained by the special design of the electronic part, the software algorithm and modes of the microcontroller operation. The most of the time the microcontroller is put into a “deep sleep” mode and turns off the “1-Wire” interface and SD-card power supply. That operation saves the battery life.

USER INTERFACE

The measuring module has a simple user interface of two buttons and one LED lamp. Their functions are to start and stop the measurement, as well as for any system indications. The operating mode parameters are set via USB connection to a PC. It uses serial terminal interface in text mode. The terminal commands are presented in Table 1.

Table 1. Terminal command set

Type	Name	Description
get	mperiod	Prints the time between measurements. The value is returned in seconds.
get	search	Performs search procedure of connected sensors and prints a list of ROM addresses.
get	time	Prints the system time of the device.
get	flist	Prints list of files that are on the SD card with extension “*.txt”.
get	file	Prints the contents of the file with the given name. Example: *get file dat_0020.txt*
get	snum	Prints the number of sensors.
set	mperiod	Sets the time period between measurements in seconds. Example: *set mperiod 10*
set	time	Sets the system time of the device. Example for 10:00:00 1 March 2016: *set time 10 0 0 1 3 16*
set	start	Starts measurement
set	stop	Ends measurement
set	delete	Deletes the given file by its name. Example: *set delete dat_0025.txt*

The user can obtain information on current operating parameters and/or to reassign a new one through the serial terminal interface. The command format is:

<command type> <command name> <parameter 1> <parameter 2> ... <parameter n>,

where the string "*command type*" can be both: "*set*" - recording the settings or "*get*" - reading the settings.

The system is able to measure the gradient of the wax temperature along the containers. To achieve the necessary precision the sensors must be located in a fixed positions inside the wax. The proposed solution to this problem is through the use of bamboo sticks as a carrier for the sensors (Fig.6).

Special attention is paid to minimizing the impact of the thermal conductivity of electrical wires connecting the sensors. Thin enamelled, high temperature (180 °C) wires are used in the sensor network connections.

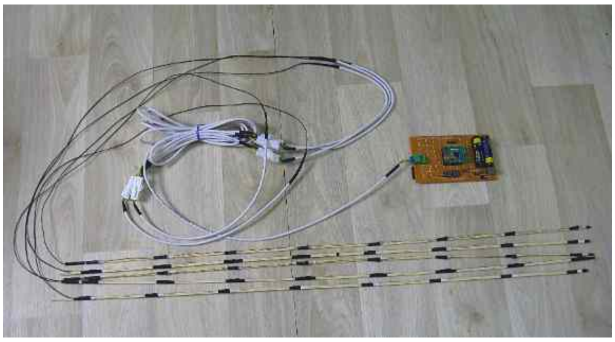

Fig.6. General view of the measurement system

EXPERIMENTAL RESULTS

Experimental measurement with 8 connected sensors of DS18S20 type was carried out for testing and validation of the system. The experimental setup, shown on Fig.7 has been arranged by using:

1. Electrical oven;
2. Container filled with cold water. At the start of the experiment the water temperature was about 20 °C;
3. 8 sensors put into the water at different depth. The sensor spacing was 120 mm;
4. Measuring module;
5. PC, equipped with terminal software.

The number of acquisitions was 71 with time interval of 20 s. The test system simulates the charging mode of the thermal water storage. The heat flux, delivered by the oven passed from bottom part of the container to the top. The collected data was transferred via USB/serial terminal interface and saved as a plain text file. The visualized data is presented on Fig.8 and shows clear picture of the thermal field inside the storage container.

Fig.7. Test measurement setup

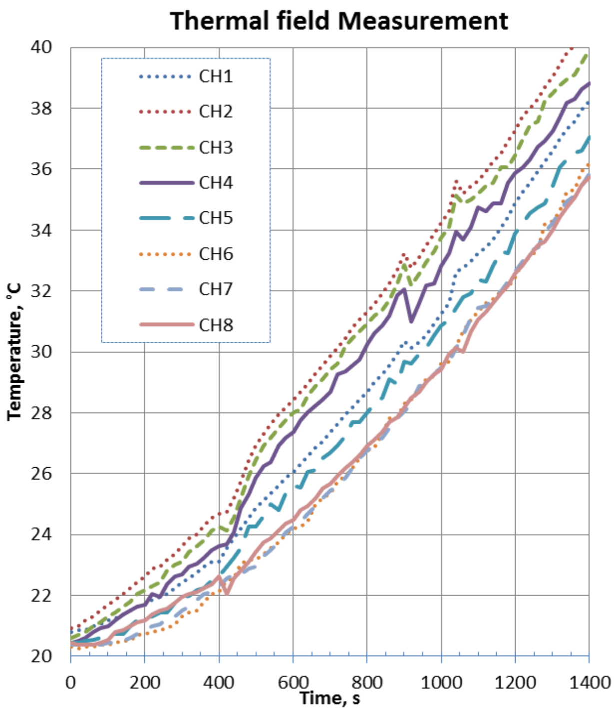

Fig.8. Test measurement results

There can be noticed a marked stratification in temperature along the depth. The sensor accuracy reports the value of ± 0.5 °C in the full temperature range of -20 °C to +125 °C and ± 0.2 °C in the temperature range of 0 °C to +80 °C.

CONCLUSIONS

The specialized measurement system, that enables long-term (up to one month) recording of temperature data in more than 100 points has been developed in the Technical University of Sofia, Plovdiv Branch. The system's functionality has been approved by real experiments and the following conclusions are made:

1. The system is compatible for analyzing thermal fields in the hybrid systems equipped with thermal energy storages with PCM;

2. Large amount of data may be stored in the SD-card and by specialized software it can be transferred via USB interface to the PC, where the thermal fields could be visualized;

4. The small size sensors are placed into tested area by the way not influencing its thermal field;

5. The measurement system is also suitable to investigate the thermal fields in related applications like chemical and biochemical reactors and columns, if the temperature is in the range of -20 °C to +125 °C.

ACKNOWLEDGEMENTS

This work has been supported financially by the research project 152ПД0045-24/ 26.03.2015 and the research project 152ПД0046-24/ 27.03.2015 of the Technical University of Sofia, which is gratefully acknowledged by the authors.

LIST OF ABBREVIATIONS

CISC – complex instruction set computer;
EPROM – electrically programmed read only memory;
HVAC – heating, ventilation and air conditioning;
I^2C – (IIC) inter-integrated circuit (interface);
LED – light emitted diode;
NTU – number of transfer units;
PC – personal computer;
PCM – phase change material;
RAM – random access memory;
RISC – reduced instruction set computer;
ROM – read only memory;
SD – secure digital;
SPI – serial peripheral interface;
SRAM – static random access memory;
USB – universal serial bus.

REFERENCES

1 T. Bocklisch, Hybrid energy storage systems for renewable energy applications, 9th International Renewable Energy Storage Conference, IRES (2015).
2 E. Milisic, Modelling of energy storage using phase-change materials (PCM), Master's Thesis, Norwegian University of Science and Technology, July 2013.
3 A. V. Waghmarea, A. T. Piseb, Numerical investigation of concentric cylinder latent heat storage with/without gravity and buoyancy, The 7th International Conference on Applied Energy – ICAE2015.
4 Z. Gong, A. Mujumdar, Finite-element analysis of cyclic heat transfer in a shell-and-tube latent heat energy storage exchanger, Applies Thermal Engineering Vol. 17, No 6, pp. 583-591, 1997.
5 N. A. M. Amin, M. A. Said, A. Mohamad, M. S. Majid, M. Afendi, R. Daud, F. Bruno, M. Belusko, Mathematical modeling on thermal energy storage systems, Applied Mechanics and Materials Vol. 695 (2015) pp 553-557.
6 S. Bellana, J. Gonzalez-Aguilara, M. Romeroa, M. M. Rahmanb, D. Y. Goswami, E. K. Stefanakos, Numerical investigation of PCM-based thermal energy storage system, International Conference on Concentrating Solar Power and Chemical Energy Systems, SolarPACES 2014, pp 758 – 768.
7 http://www.omega.co.uk/pptst/AQM-101.html.
8 http://www.pcsensor.com/software-d6.html.
9 CAS2500-26-UL- 1-Wire Data Client. Chipkin Automation Systems: www.chipkin.com.
10 A. Stoyanov, A. Georgiev, R. Popov, Experimental installation for investigation of latent heat accumulator as a part of hybrid system for air-conditioning
11 PIC18F47J53 Family Data Sheet.
12 A. Parmar , D. Kumar, I. Bala, Comparison between RISC and CISC, International journal of innovative research in technology, Volume 1, Issue 12 ISSN: 2349-6002, 2015.
13 Springbok Digitronics, 1-Wire Design Guide v1.0, 2004.