ENERGY BALANCE AND OPERATING FEATURES OF THE HEAT ACCUMULATOR

P. Fiala, I. Běhunek, E. Kadlecová

Department of Theoretical and Experimental Electrical Engineering,
University of Technology Brno, Kolejní 2906/4,612 00 Brno, Czech Republic
e-mail:fialap@feec.vutbr.cz

Summary There are described design and realization of a heat accumulator in the article which joins advantages and eliminates disadvantages of water and gravel accumulators. Inside the accumulator there are suppressed heat convection and conduction between layers of storage matter, so there is the temperature stratification along a height of such accumulator. The article deals with operating features as well.

1. INTRODUCTION

The sun is the source of nearly all energy in the world. We use solar energy in two basic forms. One form is an electrical energy (after PV cell conversion) and the second form is heat energy. The sunshine fluctuates during cycles of day-night, summer-winter etc. The fundamental claim on solar energy efficiency is the necessity of energy storage in electrical and heat accumulators. The problem with solar heating is a need to store solar energy during the day/summer for use at night/in winter or whenever the need arises.

2. DESIGN OF ACCUMULATOR

Under research project MSM 0021630516 and FRVŠ 1600/2004-G1 there was designed and constructed a model of heat accumulator for low-temperature storage in the laboratory of unconventional energy changes at Department of Electrical Power Engineering, FEEC, BUT. The aim of the design is to join advantages and eliminate disadvantages of water and gravel accumulators. Desired features are:

- high density of energy storage (small size of accumulator)
- no transmission of heat by convection and conduction between plastic enclosures
- charging and discharging at constant temperature
- ability to utilize PCM (Phase Change Material) for storage matter
- ability to use PT collectors (cheap, an easier application, less amount of heat exchangers)
- cheap, accessible, ecological.

The model is similar to gravel accumulator conceptually. It consists from several layers and between them there is thermal insulation. The basic difference is that there are plastic enclosures instead of stones, which contain matter with bigger specific heat.

The model consists of eight layers (Fig. 1). PET plastic bottles create elements with the volume of 1 liter. There are 18 PET in each layer, so the total volume of accumulator is 144 liters. Firstly water was used as storage substance, and then phase change materials were used. There is a system of swinging distributing flaps in the vertical ducts. They can direct air to layers, close and isolate layers etc.

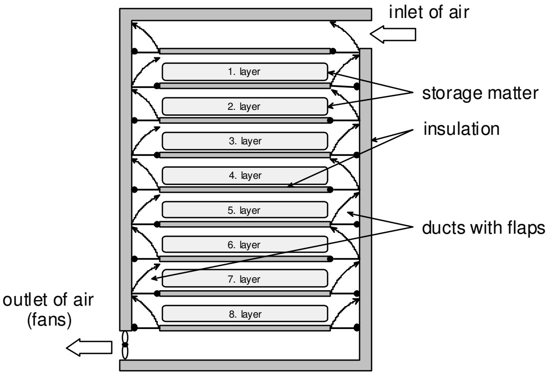

Fig. 1. Draft of heat accumulator with suppressed heat convection

3. ENERGY BALANCE AND EFFICIENCY

We calculate power and energy balance with the help of known temperatures and mass of air flow in the accumulator. Input power is

$$P_{in} = Q_m c(T_{in} - T_a), \tag{1}$$

where Q_m is mass of air, c specific heat, T_in input temperature of air and T_a temperature of room. By analogy we calculate output power (difference of $T_\mathrm{out} - T_\mathrm{a}$) and power distribution in the each of layers. Stored heat in one layer is

$$Q = 18m \int_{T_0}^{T_e} c dT, \tag{2}$$

where m, c are weight and specific heat of storage matter in one PET bottle, T_0 initial and T_e temperature at the end of charging. Charging capacity of accumulator is

$$C_{ch} = Q_{m,ch}\int_0^{t_c} c(T_{in}-T_{out})dT - \int_0^{t_c}\phi\, dt. \qquad (3)$$

Quantities Q_m, c, T_{in}, T_{out} stand for air, t_c is time of charging. Integral on the right side of equation means heat losses of accumulator during charging process. Losses are determinated from Fouriers law for heat conduction and from equation for heat transmission

$$\phi = \frac{A(T_i - T_a)}{\sum\limits_i \frac{1}{k_i} + \sum\limits_i \frac{h_i}{\lambda_i}}, \qquad (4)$$

where ϕ is power flow of losses, A area, T_i temperature inside of accumulator, k overall heat transfer coefficient, h thickness of wall, λ thermal conductivity coefficient. Discharging capacity

$$C_d = Q_{m,d}\int_0^{t_d} c(T_{out}-T_{in})dT, \qquad (5)$$

where t_d is time of discharging. When we compare charging and discharging capacity of accumulator we get the efficiency at specific time of storage

$$\eta = \frac{Q_{m,ch}\int_0^{t_c} c(T_{in}-T_{out})dT - \int_0^{t_c}\phi\, dt}{Q_{m,d}\int_0^{t_d} c(T_{out}-T_{in})dT}. \qquad (6)$$

In the Fig. 2 there are results of measuring and calculated values. Measuring was done for charging time 2, 4, …, 12 hours. Input heat power was about 800-850 W, temperature of inlet air was round 47-51 °C, discharging time was 12 hours. W_{in} is delivered heat into input of accumulator during charging time. W_{out} is leaked heat from outlet of accumulator during charging. W_{in} and W_{out} are calculated by means of the comparison of input and output temperature with ambient temperature. Delivered heat W_{del} is calculated as a difference between W_{in} and W_{out}. The real stored energy is W_{acu}. The red hatched area means heat losses during charging and they are caused by losses through walls and mixing of hot and ambient cold air in the inlet due to untightness. The blue hatched area means heat losses during discharging. Discharging capacity of accumulator is W_{gain}. If we compare W_{acu} and W_{del} we get charging efficiency η_{in}. Discharging efficiency η_{o1} is given W_{gain} / W_{del} and covers also the charging losses in contrast to efficiency η_{o2} which is calculated as W_{gain} / W_{acu}. This efficiency compares real heat which we get during discharging process and stored energy during charging without heat losses during discharging. This efficiency reflects the equation (6). We can reach better efficiency by means of two ways:

- improvement of thermal insulation
- decrease in temperature of storage.

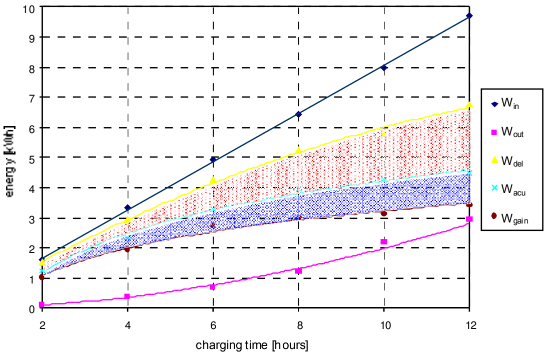

Fig. 2. Energy balance of accumulator

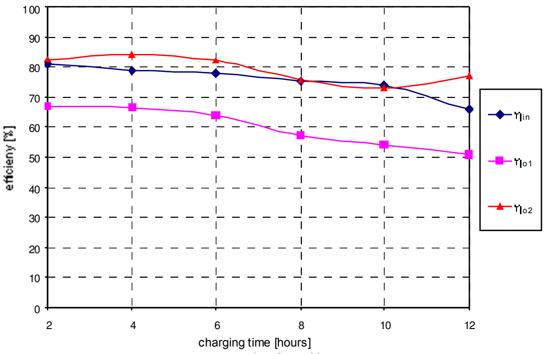

Fig. 3. Effeciency of accumulator

Fig. 3 and 4 show efficiency during charging and discharging. We were interested in ability of accumulator to keep heat as well. So we had been charging accumulator as long as we reached its maximum capacity about 5 kWh and we measured how the mean temperature decreased. Picture 4 shows the process of cooling due to heat losses.

Fig. 5 shows calculated efficiency of ability to keep heat. There is its dependence on the difference between ambient and inside temperature and on time in the picture.

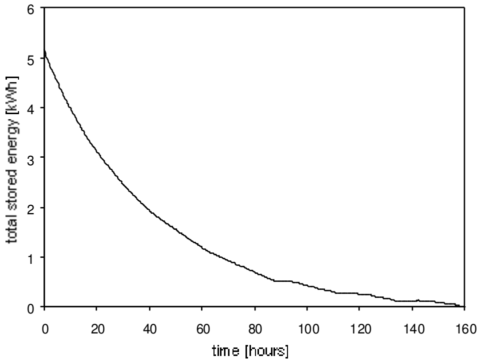

Fig.4. Decrease of total stored energy

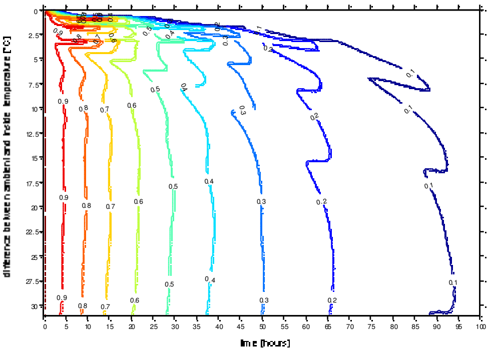

Fig. 5. Efficiency dependence on temperature difference and time

There is a snap of accumulator in the fig. 6 which was taken at the highest inside temperature (51 °C). We can see where the biggest loss heat fluxes are.

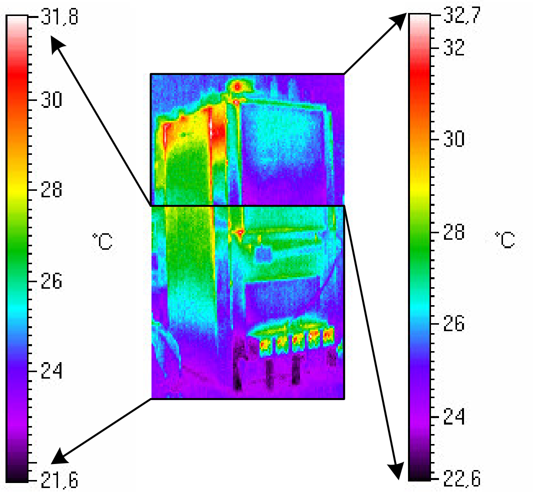

Fig.6. Distribution of temperature on the surface of accumulator

4. OPERATING FEATURES

The solar system consists of thermal collector, air manifold and accumulator. We were interested in the influence of temperature stratification when climatic conditions change. Each of layer contents 18 liters of water in PET bottles but just in the third layer there are 9,36 l of $CaCl_2.6H_2O$ in PVC pipes. Measuring was under way in the summer when the highest temperatures and solar intensity are.

First measuring is from 16.6. 2005. The weather was cloudy with maximum temperatures lower than 30 °C. Fig. 7 shows mean temperatures of layers and inlet temperature of air T_{in}. We can see rapid fluctuations in the afternoon. Black crosses mark instant of time where we should have done adjusting by means of flaps. This means to direct air into the layer which has the lower temperature than air in order not to cool warmer layers. We did not do it so we can see how the energy is wasted.

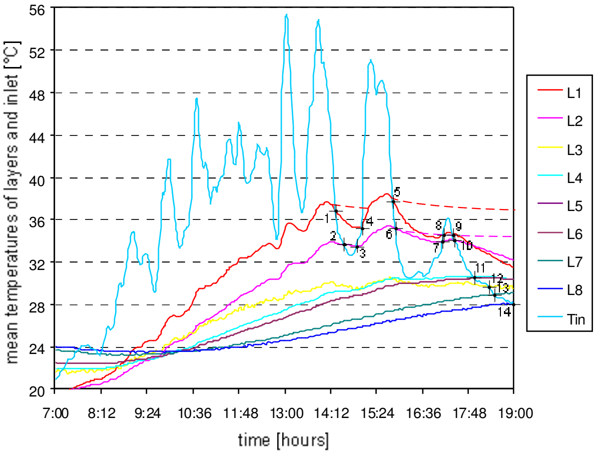

Fig. 7. Temperatures of layers and inlet (16.6. 2005)

In the next picture there is time behavior of solar intensity I and heat output from collector P_{col}. We computed W_{sun} (sun energy on the area of collector, 2 m^2), W_{col} (heat from collector) and W_{acu} (stored energy).

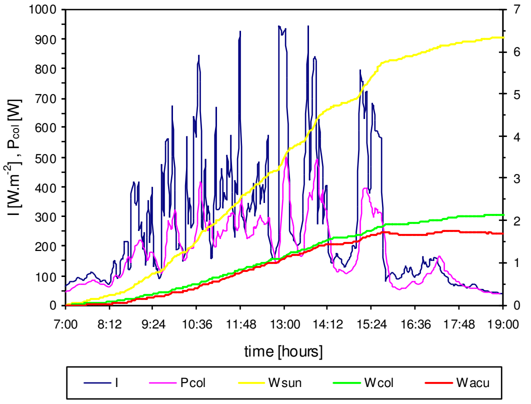

Fig. 8. Energy balance (16.6. 2005)

Next measuring is from 18.6. 2005. The weather was sunny and we did not change the configuration of swinging flaps again. We can see phase change of $CaCl_2.6H_2O$ in the third layer.

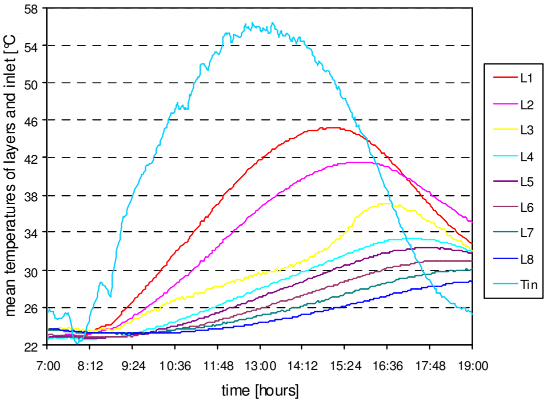

Fig.9. Temperatures of layers and inlet (18.6. 2005)

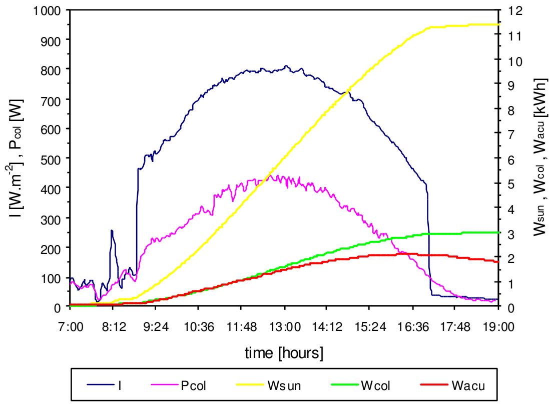

Fig. 10. Energy balance (16.6. 2005)

Last measuring is from 20.7. 2005. It was cloudy day and we decided to change configuration of flaps according to temperature of inlet air. In the late afternoon we shut layers which were warmer than inlet air and we isolated them by degrees.

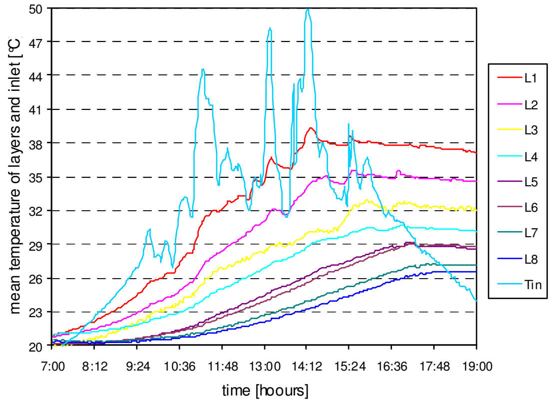

Fig. 11. Temperatures of layers and inlet (20.7. 2005)

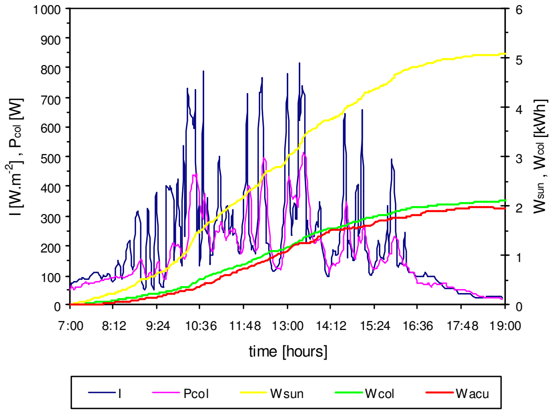

Fig. 12. Energy balance (20.7. 2005)

We can see the positive influence of temperature stratification. The results and comparison of all measuring are summarized in the table 1.

Tab. 1. The summarization of results

date	W_{sun}		W_{col}		W_{aku}	
	kWh	%	kWh	%	kWh	%
16.6.	6,33	100	2,14	33,86	1,70	26,83
18.6.	11,40	100	2,99	26,26	1,81	15,86
20.7.	5,07	100	2,10	41,35	1,95	38,35

5. CONCLUSION

The article dealt with design and operating features of the heat accumulator with suppressed convection. We can see that due to using of temperature stratification the better efficiency of storage is reached.

Acknowledgment

The paper was prepared within framework of the research plan No. MSM 0021630516 of the Ministry of Education, Youth and Sports of the Czech Republic.

REFERENCES

[1] BĚHUNEK, I. Accumulators for solar thermal energy storage. In Student EEICT 2004. Student EEICT 2004. Brno(Czech Rep.): BUT, FEEC, 2004. ISBN 80-214-2636-5.

[2] BĚHUNEK, I. Operating features of accumulator for solar thermal energy storage. In Student EEICT 2004, Bratislava(Slowakia): SUT in Bratislava, FEI, 2004. ISBN 80-227-2057-7.

[3] FISHER, L.S. *The thermodynamics and some practical aspects of thermally layered heat storage in water.* Turnberry (Scotland): NATO Science Commitee Conference on Thermal Energy, 1976.