OAK RIDGE NATIONAL LABORATORYOPERATED BY MARTIN MARIETTA ENERGY SYSTEMS, INC.
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DATE: December 19, 1990

SUBJECT: Report of Foreign Travel of John J. Tomlinson, Manager, Thermal Energy Storage Program, Engineering Technology Division

TO: Alvin W. Trivelpiece

FROM: John J. Tomlinson

PURPOSE: The DOE is developing Thermal Energy Storage (TES) technologies for heating and cooling applications in buildings and industry. The purpose of this trip was threefold: (1) to review ongoing TES research in Germany and Sweden as part of the International Energy Agency (IEA) Annex V on full scale latent heat storage installations, (2) to discuss the development and manufacture of an advanced high temperature TES material for testing in the United States, and (3) to represent DOE at an IEA Executive Committee meeting in Paris.

SITES VISITED:	12/3-4/1990	KFA Forschungszentrum	Jülich, Germany	V. Lottner D. Steiner M. Brunk B. Sellberg C. Eildermann
	12/4/1990	Didier-Werke AG	Wiesbaden, Germany	C. Streuber
	12/5-6/1990	Organization for Economic Co- operation and Development	Paris, France	E. Morofsky V. Lottner F. Reale G. van Mourik A. Snijders B. Sellberg M. Brunner B. Matthey

ABSTRACT: Recent results from selected TES research activities in Germany and Sweden under an associated IEA annex are discussed. In addition, several new technologies for heating and cooling of buildings and automobiles were reviewed and found to benefit similar efforts in the United States. Details of a meeting with Didier-Werke AG, a leading German ceramics manufacturer who will provide TES media necessary for the United States to complete field tests of an advanced high temperature latent heat storage material, are presented. Finally, an overview of the December 1990 IEA Executive Committee meeting deliberations on TES is presented.

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International Energy Agency (IEA) Annex V Experts Meeting, Jülich, Germany, December 3-4, 1990

For the past several years, the United States, Germany, and Sweden have been working to develop and demonstrate TES technologies to meet heating and cooling demands of buildings and industries. Under Annex V of the IEA, each country is responsible for a technical task; results from each task are assimilated and evaluated by the IEA, and a report is distributed to the membership. The IEA Annex V Experts Meeting for 1990 was held in Jülich, Germany (near Köln), on December 3-4 and was attended by representatives from Germany, Sweden, and the United States.

The meeting was attended by C. Eildermann (of what was once East Germany), who is one of the developers of an interesting TES system for space heating. This system, termed Galisol (for gas-liquid-solid), uses reflux boiling of a heat transfer fluid (R-113) through sodium acetate which is used as the phase change material (PCM). The system is "charged" with thermal energy through a coil located at the bottom of the storage tank and is discharged through a coil located in the vapor space in the top of the tank. Eildermann indicated that the storage density was 3 to 8 times that of water depending on the temperature range used for comparison. This range is similar to that found in ORNL tests of ice storage systems for building cooling. It appears that about 20 Galisol systems have been installed; not all have been commissioned. One of the more interesting installations was in a ship in which the system was being used to recover engine heat for use in cabin heating. The Galisol system has been licensed by Japan for use in the chemical industry and water filtration and milk pasteurization processes. In view of the restrictions on R-113, other heat transfer fluids, including bromoethane and chloroform, are being evaluated. In terms of economics, a 65 kWh Galisol system costs 6000DM. This is approximately \$60/kWh which is about twice the allowable cost in the United States based on similar applications and reasonable economic assumptions.

Dieter Steiner (Germany) reported continued testing and evaluation of the Galisol system. Steiner noted that although the measured storage capacity (73 kWh) was found to be equal to that expected from the inventory of PCM, the performance of the system during discharging (solidification of the PCM) was not consistent from one test to another. This was evidently the result of stochastic behavior in nucleation of the PCM. A thermal model of the Galisol system constructed by Steiner was calibrated using experimental data and was used to predict the delivery temperatures from the storage unit. It was found that the model accuracy was only as good as the range in experimental data used to calibrate the model. This was not unexpected.

I was interested to learn from Steiner that the Institut für Kernenergetik und Energiesysteme in Stuttgart, with support from the German Ministry and Mercedes Benz, is working to develop a TES system for preheating cold automobile engines. This was of interest to me since cold starting problems have been found with methanol fueled engines in the DOE Alternative Fuels program. In the system under investigation by Steiner, waste heat from the exhaust is stored as sensible heat in a water/glycol mixture. The mixture is stored in a pressurized insulated container under the hood of the car. On cold mornings, heat from the mixture quickly brings the engine up to normal operating temperature for an overall reduction in exhaust emissions and improved engine efficiency. Steiner noted that at the current state of development, heat losses from the system were higher than acceptable, and the system was too bulky to be easily located under the hood. Steiner also indicated that a similar system is under development by Schatz Thermo Engineering for Volkswagen (VW). This more advanced system uses latent heat storage in barium hydroxide which is contained in a heavily-insulated annulus surrounding one of the coolant lines from the engine. During normal operation of the vehicle, heat from the coolant is

stored at 70°C by melting the PCM. At a later time, the stored latent heat can be used to preheat the engine, warm up the passenger compartment, and defrost the windshield. The VW system is surprisingly compact and efficient; standby heat losses in the charged state are 4 W (-20°C ambient temperature); storage capacity is 1 kWh; the weight of the unit is 10 kg including 3 kg of insulation. Testing and development results of the Schatz system will be presented by Oskar H. Schatz at the SAE meeting in February 1991. Schatz also has an office in Detroit (313-649-2292).

Björn Sellberg reported on the Swedish experience with a latent heat storage system to provide off-peak cooling in a large office building in Stockholm. The storage system is a standard design according to Cristopia, the manufacturer. It consists of a 25m³ tank filled with small plastic balls. The balls are filled with a liquid which changes phase at 0°C. The liquid can be summarized as water with a small quantity of additives to lower the surface tension and facilitate freezing. The diameter of a ball is 70 mm and inside the ball there is an air-pocket that allows for expansion of the liquid as it freezes. The shell is of plastic, and the filling hole is welded after the ball has been filled. Brine is used as the heat transfer fluid surrounding the balls in a horizontal pocket bed arrangement. In the summer of 1988, measurements proved that the liquid in the balls did not freeze at the brine charging temperature of -5°C. The measurements were complemented by laboratory tests on two reference balls that had been taken from the storage system. These tests showed the same behavior. The liquid in the balls could be supercooled to -4.5°C or more without freezing the ball. However, a certain randomness was observed in the freezing process.

The balls were replaced by the manufacturer, and testing of the storage system was resumed. It was found that the performance of the system improved; however, the capacity of the storage system remained lower than expected. Apparently the entire latent heat capacity of the storage system was not realized due to inadequate heat transfer at the surface of some of the balls. Efforts to decrease the brine temperature to the storage tank during charging were mostly ineffective due to restrictive chiller temperature controls and the proximity of the storage working temperature to the freezing temperature of the brine. Sellberg also reported on his experience with Cristopia balls that were made to freeze at -12°C. A TES system of such balls had been installed in a warehouse in Stockholm and used to provide off-peak cooling. Again, the experience was somewhat disappointing as both the storage system capacity and the rate at which cooling was delivered from the TES system were found to be less than expected. Sellberg pointed out that even if the storage system had operated as expected, the system economics were not favorable. High installed system costs were not offset by the difference between on- and off-peak electricity costs over a reasonable period. Demand charges were not available under the rate structure available to the building. These findings are not inconsistent with what we find in the United States. In general, the real benefit to be gained by implementation of cool storage in commercial buildings is reduction in peak demand. On this basis, it is the reduced electric costs due to demand reductions during on-peak periods (rather than time-of-day rate differentials) that provide the economic incentive for cool storage. In addition, many utilities in the United States provide further encouragement of cool storage through direct subsidies and other inducement programs.

There is growing German interest in commercial building cool storage using ice. At the Annex V meeting, Mr. Brunk (project director with the German engineering firm TKT) described a cool storage system and other innovations that had been installed recently in the Deutsche Bank in Köln. On the second day of the meeting (December 4) we toured the bank to see these installations. The ice storage system there was operating and was at the point of being accepted by the building owner. Interestingly, the ice tank and evaporator had been manufactured by Baltimore AirCoil - one of the largest manufacturers of ice storage systems in the United States.

Due to space constraints, the system had been built in place in the basement of the bank; system maintenance such as coil replacement will not be straightforward. The refrigeration system used conventional pumped recirculation technology and had been designed and installed by Linde.

Another feature of the Deutsche Bank was a unique space cooling system that had been designed by the TKT. The system consists of cooling coils inside of ceiling panels and a clever fresh air ducting system along the structural columns of the building. Chilled water is continuously circulated through the ceiling coils thereby cooling the occupied space beneath. Major advantages of this approach are the small amount of space required for the cooling system (i.e., no ceiling plenum is required) and the ease with which cooling zones can be maintained. In a real sense, the occupants are cooled by radiative heat exchange between themselves and the ceiling. The room felt very comfortable and was quiet (no fans or air diffusers in the ceiling). Low humidity fresh air was provided to the occupied space by large, low airflow registers that had been integrated into the supporting columns in the building. The humidity of the supply air was closely controlled to keep the air adjacent to the ceiling panels above the dew point. Although the system appeared to be working quite well, the potential for damage to the interior walls, ceilings, and floors from problems such as leaks in the ceiling panels or loss of supply air humidity control is high. Still I feel that systems such as this deserve consideration as a design option for buildings in the United States.

I reported on the status of the United States contribution to Annex V: demonstration of an advanced high temperature TES system for industrial waste heat regeneration. Although changed somewhat from the large, full-scale test/demonstration project initially planned in a periodic brick plant, the project is continuing. Under subcontract to the ORNL TES program, Mississippi State University (MSU) has designed and is constructing a high temperature packed bed TES test facility that will use flue gas to charge (heat up) an inventory of TES material. The packed bed test section is a right circular cylinder 0.6m in diameter. The facility can provide flue gas at temperatures up to 1100°C; discharge of the packed bed is done using ambient air as the cooling fluid. The bed can be discharged by co-current or counter-current operation. The facility is currently under construction. One of the central objectives of the test program is the evaluation of a composite TES material which has been carried through laboratory development in the United States by the Institute of Gas Technology. The material to be used for the upcoming tests will be obtained from the German firm Didier-Werke AG under an agreement with Energy Systems.

Meeting with Didier-Werke AG in Wiesbaden, Germany, December 4.

In the afternoon of December 4, I met with C. Streuber of Didier-Werke AG in Wiesbaden to discuss arrangements for delivery of high temperature test media to the United States for the packed bed tests to be conducted at MSU in 1991. As Didier is interested in reducing the size of blast furnace recuperators (cowpers) in steel plants, they are working on a high temperature composite similar to the material developed by the Institute of Gas Technology under the DOE TES program. Although the matrix for the composite examined by the United States is magnesium oxide, Didier has had better luck with silica. As a first test under the DOE program, a sensible heat storage material in the form of pellets would be tested by MSU to verify a packed bed thermal model and to calibrate instrumentation in the test facility. Subsequent tests would be performed on a high temperature composite consisting of the magnesium oxide matrix containing a carbonate eutectic that melts at 700°C. I discussed our testing plans with Streuber and indicated the quantity and type of test material that we need. He indicated that the sensible heat storage media could be zirconium oxide delivered from a Didier plant in the United States; delivery of the composite media would be from Germany at a later time. Streuber agreed to examine the available options for the material and its delivery to the test site and to contact me with this information in 2 weeks.

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IEA Executive Committee (EC) Meeting on Energy Storage, Paris, December 5 - 6, 1990

Following the above meetings in Germany, I substituted for R. Eaton (DOE-HQ) at a two-day Executive Committee meeting of the IEA in Paris. The following notes were taken at this meeting and are presented for the record.

The meeting was called to order by Chairman G. van Mourik. Represented were Canada, Germany, Italy, The Netherlands, Sweden, Switzerland, and the United States; not represented were Denmark, Finland and Belgium. The minutes of the last EC meeting were read and approved with minor changes. Chairman van Mourik reported that a brochure describing the seasonal TES research performed by the member countries under Annex VI has been drafted and is out for comment. He noted that Denmark had suggested that any mention of well-plugging problems with TES in underground aquifers be restricted to high temperature systems. Apparently, plugging in low temperature systems is not a problem. All participants (a group of countries which includes the United States) in Annex VI were asked to provide comments on the brochure as soon as reasonable. The chairman also indicated that a draft of the EC annual report had been drafted.

The work under Annex III was reported by B. Matthey (Switzerland). He noted that the objective of this annex, now in its 10th year, was to show that it is possible to store thermal energy in an underground aquifer. He reported that this has been done through projects in Denmark and Switzerland. He distributed a brochure describing the Swiss project (SPEOS) and indicated that a draft of the final report of the projects under Annex III has been written and is under review. Since the objective of Annex III was attained, Matthey recommended that the annex be closed out; Chairman van Mourik accepted this recommendation.

Progress in IEA Annex V was reported by V. Lottner (Germany). Details of this annex were described earlier in this report. Lottner pointed out that the annex will be completed at the end of 1990 with a final report consisting of contributions from member countries. A brochure of the results of Annex V will be prepared as well.

A status report from Annex VI was presented by A. Sniijders (The Netherlands). He pointed out that the 7th annual experts meeting for Annex VI was in Ottawa on November 1, 1990; the next experts meeting will be May 21-23, 1991, in Stuttgart, and will be followed by a meeting during the period November 27-29, 1991, in La Chaux-de-Fonds, Switzerland. The member countries are Canada, Denmark, Finland, Germany, The Netherlands, Sweden, Switzerland, and the United States. He indicated that a final phase I survey report of the participating countries will be written in March 1991; final evaluation of phase II of the projects will be completed in June 1992. The United States' contribution to this annex consists of evaluation of ion exchange methods to treat wells connected to aquifers. This work is being performed at Pacific Northwest Laboratories (PNL). Sniijders also presented an overview of a workshop on aquifer TES held in April 1990. The purpose of the workshop was to evaluate available experience with high temperature (>80°C) and to identify future R&D needs.

Annex VII to study innovative cool storage techniques primarily for building cooling was described by E. Morofsky (Canada). The annex, although not yet formally approved by the IEA, is being supported by The Netherlands, Germany, Sweden, and Canada where work is underway. The IEA is considering formal adoption of this annex but, as of the meeting date, has made no decision.

There was some discussion concerning the need for an annex on environmental effects on new energy systems such as TES. It was pointed out that several ECs of the IEA are also working on tasks connected with issues such as CO₂ production and atmospheric O₃ reduction from refrigerant use. The chairman accepted responsibility for contacting allied ECs for background information and to prepare a strawman annex work statement for comment and ratification by the full EC.

As the last item at the meeting, E. Morofsky (Canada) was elected chairman of the EC and F. Reale (Italy) accepted the position of vice-chairman on a temporary basis. Chairman Morofsky indicated the need for a long range plan for the EC and accepted the responsibility of completing a second draft of this plan based on work initiated at the last EC meeting six months ago.

APPENDIX A

Itinerary

12/2/90	Depart Knoxville to Frankfurt
12/3/90	Arrive Frankfurt; travel by rental car to Jülich, Germany
12/3-4/90	KFA Forschungszentrum - Jülich, Germany
12/4/90	Travel by rental car to Wiesbaden, Germany, then by train to Paris
12/5-6/90	IEA Executive Committee Meeting - Paris
12/7/90	Depart Paris to Knoxville

APPENDIX B

List of Persons Contacted

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APPENDIX C

Biographical Listing of Literature Received

Literature Acquired:

1. A. Carotenuto, G. Ruocco, and F. Reale, *Thermal Storage in Aquifers and Energy Recovery for Space Heating and Cooling*, DETEC, University of Napoli Federico II, February 1990.

END

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