

EARTH HEAT PIPE WORKING WITH CARBON DIOXIDE STATUS OF DEVELOPMENT

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Abstract: After the fundamental investigations on an earth heat pipe working with carbon dioxide have been dealt with already at the last IEA Heat Pump Conference in Las Vegas, the further development of the patented novel system up to market introduction will be described.

Preliminary measurements in comparison to a conventional brine earth probe have been performed and evaluated showing the energetic advantage of the CO₂ heat pipe system because of the better heat transfer properties of the fluid carbon dioxide and the pump less working principle of a vertical thermosyphon as compared to a brine earth probe. A dozen heat pumps with such CO₂ earth heat pipes have been installed at one family houses until 2007 and worked now since 2005 already up to three heating seasons successfully.

It is expected that this novel earth heat probe system will gain a certain market share in the field of geothermal heat pumps because of the not ground water affecting working fluid CO₂ favourable in water protection areas and because of the energetic advantages of the working principle with this fluid.

Key words: *Cabondioxide Earth Probe, Earth Thermosyphon, Earth Heat Pump, Corrugated Heat Pipe, Flexible Stainless Steel Heat Pipe, Carbondioxide Falling Film Thermosyphon*

1 INTRODUCTION

FKW has performed R&D work since 1998 on a CO₂ earth heat pipe system with patent application on December 24, 1998 (No. DE 19860328.2-15). Initial results of this R&D work have been published at the 8th IEA Heat Pump Conference 2005 in Las Vegas, USA (Kruse 2005). That work as described there led to the development of a special CO₂ earth heat pipe with flexible stainless steel pipes (**Figure 1**).



Figure 1: Corrugated stainless steel pipe

Corrugated stainless steel pipes of this type, (**Figure 1**), are produced commonly by the Brugg Pipe Systems GmbH, the German subsidiary of the Swiss Brugg AG Holding, for various applications like flexible and rigid pipe systems for district and local heating industry, filling stations and system packages.

The whole R&D work led up to now to the development of the “FKW-CO₂ Earth Heat Pipe,” covered by the German Patent No. DE 10327602.

After the end of the R&D work in 2004 which had been sponsored by the DBU (German Federal Foundation Environment) to FKW and its Partners Aetna Wildau and Kaeltro Berlin and as presented at the IEA Heat pump Conference in Las Vegas, field tests have been performed with 50 and 100 m long corrugated heat pipes in order to investigate the feasibility of handling and inserting them into the earth and to measure the performance together with a conventional brine earth probe for comparison.

Since 2005 around a dozen pilot heat pump systems with FKW CO₂ Earth Heat Pipes have been installed in Germany and Austria in order to gain experience in real applications at one-family homes.

In 2005 and 2006, two new R&D projects have been started, one by ElFER, the European Institute for Energy Research, with participation of FKW et al., sponsored by the electric utilities EnBW Karlsruhe, Germany, and EDF Paris, France, for measurements at a 250 m deep CO₂ heat pipe, the other one by FKW Hannover, sponsored by BMWi, the German Federal Ministry of Economy with participation of the companies Viessmann, Allendorf, ThyssenKrupp Edelstahl, Krefeld, Brugg Pipe Systems, Wunstorf/Hannover and Gea WTT Plate Heat Exchanger, Nobitz-Wilchwitz, in order to continue the former R&D work for further development of the FKW- CO₂ Earth Heat Pipe.

This paper shall describe the further work after 2004 done so far at this novel earth heat pipe system working pump less as a thermosyphon with the not ground water affecting fluid carbon dioxide, in order to demonstrate hereby the status of development.

Figure 2: CO₂ earth heat pipe

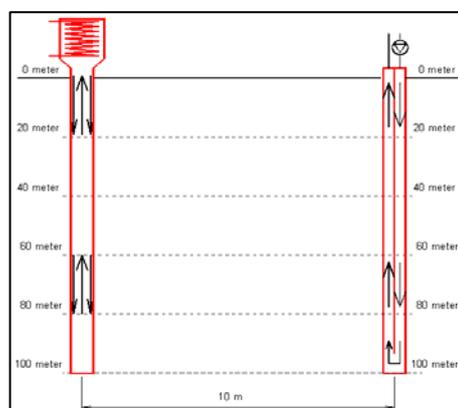


2 FURTHER DEVELOPMENT WORK

First, after having tested the feasibility, handling and inserting of the heat pipe into a 50 m deep borehole by Aetna and Kaeltro in Berlin (**Figure 3a**), at the same site performance tests of the novel 100 m deep FKW Earth Heat Pipe in comparison to a conventional 100 m deep brine earth probe with a distance of 10 m have been performed there (**Figure 3b**).



Figure 3: a) Inserting the 50 m heat pipe at Kaeltro



b) Installation of two 100 m earth probes

Both earth probes were connected to one of two identical R407C-heat pump systems, built by Kaeltro with identical scroll compressors and plate type condensers, sponsored by Copeland and Gea-Ecoflex, respectively, working in parallel on the heating system of the Kaeltro office building (**Figure 4**).



Figure 4: Arrangements of two compressors and condensers

The only difference of both heat pumps concerned the individual evaporators for the two different earth probes, namely a plate type evaporator as brine cooler on the top of the earth probe (**Figure 5a**) and a shell and coil type evaporator for condensing the CO₂ vapour on top of the heat pipe (**Figure 5b**).



Figure 5: a) Brine cooler on the top of the earth probe



b) Shell and coil heat exchanger on the top of the CO₂ heat pipe

Both heat exchangers each were designed for a cooling capacity of 5 kW according to the assumed heat extraction rate from the earth of 50 W/m depth.

The brine cooler was designed and sponsored by the manufacturer Gea-Ecoflex, Sarstedt/Hannover for this application in a brine heat pump. The other R 407C-evaporator as CO₂ condenser had been laid out and designed by FKW Hannover and physically built by its research partner Kaeltro Berlin.

Various tests with the CO₂ heat pipe have been performed in May and June 2005 by Kaeltro in Berlin according to **Table 1**, two of them with both earth probes in parallel, each continuously running for 48 and 18 hours, respectively. Another test for 7 hours has been performed in March 2006, the other tests were done for gaining some more data with the CO₂ heat pipe only.

Table 1: Results of measurements

Period	Brine Inlet Temp [°C]	Evaporating Temp. t_0 R407C [°C]* at dew line	Condensing Temp. t_c R407C [°C]* at dew line	Heat extraction rate of brine earth probe [W/m]	CO ₂ Inlet Temp. [°C]	Evaporating Temp. t_0 R407C [°C]* at dew line	Cond. Temp. t_c R407C [°C]* at dew line	Heat extraction rate of CO ₂ earth probe [W/m]
20.-23.5.05: 60 h	-	-	-	-	-1.4	-6.4	44.4	56.5
1.-2.6.05: 24 h	-	-	-	-	-3.3	-8.3	26.9	60.4
4.-6.6.05: 48 h	-1.4	-13.9	37.6	42.4	-3.9	-9.1	37.5	60.0
7.-8.6.05: 18 h	-0.5	-13.5	51.9	43.4	-3.6	-8.8	51.0	61.7
27.-30.6.05: 60 h	-	-	-	-	-0.1	-7.1	39.4	59.8
7.-7.3.06: 7 h	-	-	-	42.2	-2.0	-8.7	47.1	52.9

*) at dew line

Evaluating the test results for the period from June 4 to June 6, 2005 in more detail, the diagrams in **Figure 6** show the heat pump system temperatures on the left hand side above and the heat pipe outer wall temperature below over the elapsed test period. It can be stated that at the end of a test period of 48 hours the test conditions were sufficiently constant so that an evaluation and comparison of these test values and of the behaviour of both pipes could be done:

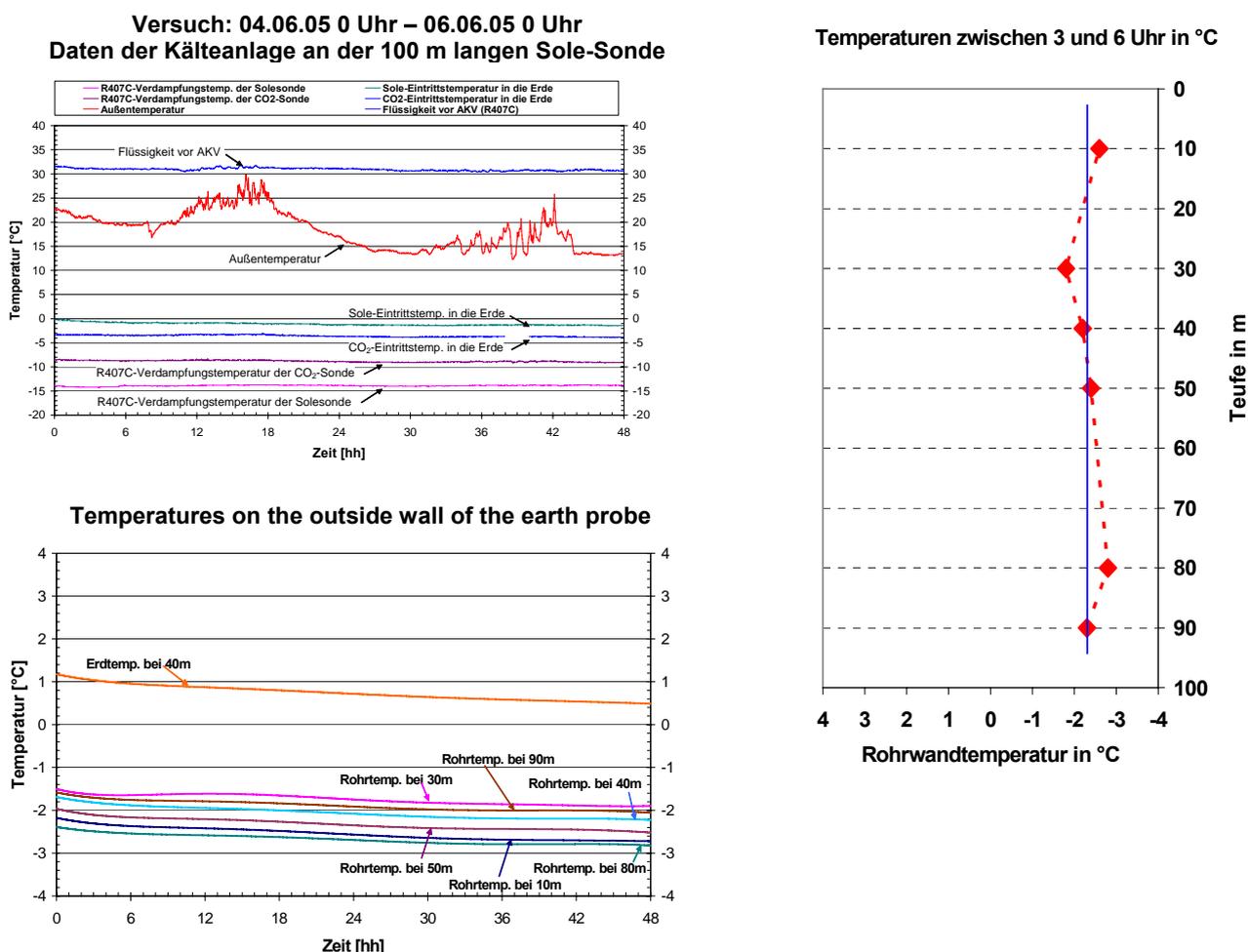


Figure 6: Measured temperatures of the heat pump and of the earth probe

First, according to Table 1, the R407C system for the brine earth probe system showed an evaporator brine outlet temperature i.e. an earth probe brine inlet temperature of -1.4°C , a R407C dew line evaporation temperature of -13.9°C , a dew line condensing temperature of $+37.6^{\circ}\text{C}$ at an earth heat extraction rate of 42.4 W per meter depth of the brine earth probe.

Secondly, the CO_2 liquid inlet temperature into the heat pipe, i.e. at the outlet of the R407C evaporator/ CO_2 condenser vessel (**Figure 7**) was -3.9°C at a R407C dew line evaporation temperature of -9.1°C , a dew line condensing temperature of $+37.5^{\circ}\text{C}$ and an earth heat extraction rate of 60.0 W per meter depth of the CO_2 heat pipe.



Figure 7: Evaporator vessel

The CO_2 heat pipe wall temperatures of the pipe down to a depth of 90 m were also sufficiently constant between -2 C and -3°C as shown in the diagram, Figure 6, over the elapsed time on the left hand side and along the depth of the heat pipe in the right hand side diagram, **Figure 8**. This indicates an even distribution of the evaporating CO_2 liquid at the inner side of the pipe wall.

In summary, it can be stated from the tests with both continuously running heat pump systems with identical components, except the carefully laid out individual evaporators for a cooling capacity of 5 kW each, that the brine earth probe showed a higher brine inlet temperature but a lower evaporation temperature in the heat pump, whereas the CO_2 heat pipe showed a lower liquid inlet temperatures but a higher evaporation temperature indicating a better heat transfer in the evaporator/condenser as compared to the brine cooler.

This different behaviour caused for the CO_2 heat pipe a higher heat extraction rate of 60 W/m because of the higher temperature difference between CO_2 liquid at the inner heat pipe wall and the undisturbed earth, as compared to the brine earth probe with 42.4 W/m with a lower temperature difference to the earth.

For testing both earth probes with the same heat extraction rate it would have been advisable to run the compressor of the CO_2 heat pipe system with an adequate lower speed in order to achieve also 42.4 W/m as the brine earth probe. This test regrettably had not been performed due to lacking of an inverter control for the compressor.

Therefore, the comparison must be made theoretically based on the measured results by adjusting the temperature difference to that amount that the extraction rate for the CO_2 heat pipe would be also 42.4 W/m like that one of the brine probe.

On the other hand by such a calculation procedure the comparison can also be made for both earth probes for the average earth heat extraction rate of 50 W/m for layout purposes in Germany.

Regarding the COP a higher value can be expected for the CO₂ heat pipe system due to the higher R407C evaporation temperature than for the brine earth probe caused by the lower R407C evaporation temperature, in each heat pump, respectively.

Since regrettably the electrical power for each compressor had not been measured an approximate comparison of this effect had been done using the FKW Recycle Program for both R407C systems with the measured mean evaporating and condensing temperatures resulting in the theoretical COP of cooling or COP of heating, respectively.

These theoretical comparisons based on the measured test results are shown in **Table 2**:

Table 2: Results

System	t _{B1}	t _{B2}	Δt _{Brine}	t _o	t _c	COP _c	COP _h	Δt _{om}	Δt _{Earth}	Q _o	l
	[°C]	[°C]	[K]	[°C]	[°C]	-	-	[K]	[K]	[W/m]	m
Brine	-1.4	+0.2	1.6	-13.9	37.6	2.81	3.81	13.3	12.3	42.4	100
CO ₂	-3.9	-3.9	0	-9.1	37.5	3.23	4.23	5.2	15.4	60	100
CO ₂	+0.6	+0.6	0	-4.6	37.5	3.71	4.71	5.2	10.9	42.4	100
Brine	-3.6	-2.0	1.6	-16.1	37.6	2.65	3.65	13.3	14.3	50	100
CO ₂	-1.3	-1.3	0	-6.5	37.5	3.50	4.50	5.2	12.8	50	100

This table shows for the different above mentioned cases of comparison for both earth probes their inlet and outlet temperatures and temperature differences, the dew line evaporating and condensing temperatures of R 407C in the heat pump cycles, the calculated Coefficients of Performance (COP) for Cooling and Heating, the mean temperature differences in the individual evaporators and further on between the earth and the earth probe liquid, as well as the heat extraction rate from the earth and finally the earth probe length.

The theoretical COP values in Table 2 are only used to compare them relatively for both systems assuming a similar COP ratio for the real values. This comparison shows the better energetic performance of the heat pump with a CO₂ earth heat pipe than with a brine earth probe. The COP for cooling is around 15% better at the tests with different heat extraction rates of 42,4 or 60,0 W/m, respectively, and 32% better at equal heat extraction rates of 42,4 W/m or 50 W/m with both probes.

The COP for heating is under the same test conditions 11% better with different heat extraction rates of 42,4 or 60,0 W/m, respectively, and 24% or 25% with equal heat extraction rates of 42,4 or 50 W/m with both probes, respectively. No brine pump power has been taken into consideration.

This improvement is based on the better heat exchange behaviour in the CO₂ condensing evaporator than in the brine cooler of the individual systems, indicated by the smaller temperature differences. Also the better heat transfer in the heat pipe itself contributes to the better energetic performance of this system as compared to the brine earth probe.

Theoretical comparisons of the Seasonal Performance Factors (SPF) of earth coupled heat pumps have been performed theoretically by A. Peterlunger and Professor Ehrbar [2] from the Buchs Technical Institute based on some otherwise measured results in a project of the Swiss Federal Office of Energy according to **Figure 8** [2].

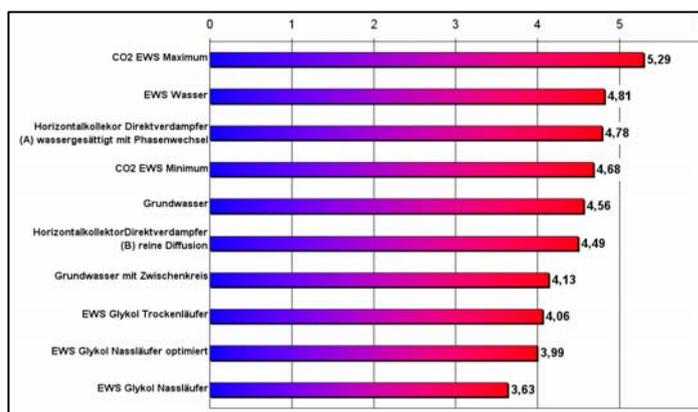


Figure 8: Comparison of SPF for different systems

Figure 8 shows the results for CO₂ heat pipe systems, ground water systems and brine systems in various configurations. The study predicted the optimized CO₂ system to be the best compared to the ground water and brine systems, whereby the latter one running with pure water is very close in the Annual Performance Factor to the CO₂ system. This water earth probe on the other hand has the disadvantage of necessary higher probe fluid temperatures in order to avoid water freezing at the evaporator exit, resulting in lower heat extraction rates from the earth, and hence longer earth probes for the same capacity.

3 PILOT SYSTEMS

After having compared in first measurements the behaviour of the conventional brine earth heat probe and the novel CO₂ earth heat pipe, both operated by continuously running identical R407C heat pumps the conclusion can be drawn that an advantage for the heat pipe can be stated concerning the heat extraction rate from the earth and the coefficient of performance COP for cooling or heating, respectively.

Therefore, further steps for continuing development of this novel pump less earth heat pipe had been made:

As next steps to gain experience with the new developed system for heating of one-family-houses it was planned in 2005 to install such systems at the locations of the individual homes in the German state of Baden-Württemberg which had started at that time a one year's programme for promotion of earth heat probe systems in general. Therefore, this was a possibility to participate in this programme with the benefit of governmental support for installing CO₂ earth heat pipes.

As pioneer to install this type of earth probes at various locations there, the Planning Bureau Stein, Bammental, installed the majority of these heat pipe systems in this region of Germany, according to Table 3.

The first one of these FKW- CO₂ heat pipes in South West Germany had been installed in Schriesheim/Odenwald on 15th September, 2005.

Another one was installed by the Ochsner heat pump company in Austria, one further system as already dealt with at Kaeltro in Berlin and a second one there at the private home of Kaeltro's owner.

In Table 3 the systems are listed according to the locations of the one-family-homes, the manufacturers of the heat pumps with the nominal heating capacity, the number and length

of the individual heat pipes with the heat extraction capacity, the properties of the underground earth and the date of starting the heat pump operation.

Table 3: Pilot systems

Location	Type of heat pump	Heating capacity	Length of the heat pipe	Cooling capacity	Sub soil	Start up
Schriesheim	Hoval DV8P	8,5 KW	1 x 100m	6,6 KW	silt/rock	15.09.05
Bad König	Hoval DV7P	5,5 KW	1 x 80m	4,3 KW	silt/rock	18.10.05
Crailsheim	Hoval DV15P	15 KW	2 x 100m	12 KW	lime stone	24.10.05
Emsbach	Hoval DV8P	8,5 KW	1 x 100m	6,6 KW	lime stone	15.04.06
Nordheim/Heilbronn	Hoval DV8P	8,5 KW	1 x 100m	6,6 KW	silt/lime stone	15.10.06
Ludwigshafen	Hoval DV8P	8,5 KW	1 x 100m	6,6 KW	sand/ground water	10.11.06
Kappelrodeck/Achern	Hoval DV7P	5,5 KW	1 x 80m	4,3 KW	silt/rock	?
Eppingen/Richen	Schrag	8,5 KW	1 x 100m	6,6 KW	silt/rock	05.07
Bammental	Hoval	8,5 KW	1 x 100m	6,6 KW	silt	11. 07.
Waldburg(A)	Ochsner	?	1 x 100m	?	?	?
Berlin	Testrig	7.5. kW	1 x 100m	5 kW	?	20.05.05
Berlin	Schrag	k. A	1 x 100m	?	?	?

In summary, it can be stated that the individual pilot systems having operated already during up to three heating seasons have not shown general problems.

4 RESEARCH PROJECTS

4.1 EIfER – Research-Project

During the year 2005 the EIfER, European Institute for Energy Research in Karlsruhe, initiated a research project which was sponsored by the both utilities EnBW, Energie Baden-Württemberg, Karlsruhe and EDF, Électricité de France, Paris, in order to investigate a 250 m deep FKW-CO₂-earth heat pipe for providing earth heat to an old existing building from only one individual deep borehole.

Partners in this project were the University of Karlsruhe, FKW Hannover, Kaeltro Berlin, and the “systherma planning bureau for earth heat systems” in Starzach-Felldorf which performed the coordination, FKW the lay out of this first very deep heat pipe system, Kaeltro the installation between heat pipe, heat pump and heating system, and the Institute for Applied Geology of the University Karlsruhe the installation of the devices for measurements in order to evaluate together with FKW the operation of the whole system.

The drilling of the borehole at Triberg (Black Forest) was done in December 2006, the heat pipe was placed into the borehole in March 2007 and, after several preliminary tests with the

whole heat pump system and the CO₂-earth heat pipe, the official starting of operation had been on January 23, 2008 [3, 4].

4.2 FKW – Research-Project

During the described former research work on the earth heat pipe of FKW and its partners the development of the heat pipe itself had been finished so far that the pilot installations could be made.

On the other hand a lot of questions still were open i.e. for example further work concerning the handling of the heat pipe, its inserting into the bore hole filled with the drilling suspension, good connection to the earth by a filler material with high heat conduction but also avoiding corrosion by selection of proper stainless steel material. Therefore, it was necessary to answer these questions before entering the market, as well as performing much better and more exact measurements for comparison of a CO₂ earth heat pipe with a conventional brine earth heat probe as formerly done by Kaeltro in Berlin.

So, it was decided to start a continuing research and development project by FKW and its new industrial partners for further improvement work on the developed heat pipe.

In 2006 such a project, sponsored by the German Federal Ministry of Economy and Technology and guided by PTJ, Projektträger Jülich, was started at FKW together with its partners Viessmann, ThyssenKrupp, Brugg and Gea-WTT for the working period between May 1st, 2007 and April 30, 2009.

For performing the necessary research and development work as also the energetic measurements for comparisons to conventional systems, FKW had decided to install three earth probes at its parking lot close to the FKW building (**Figure 9**).

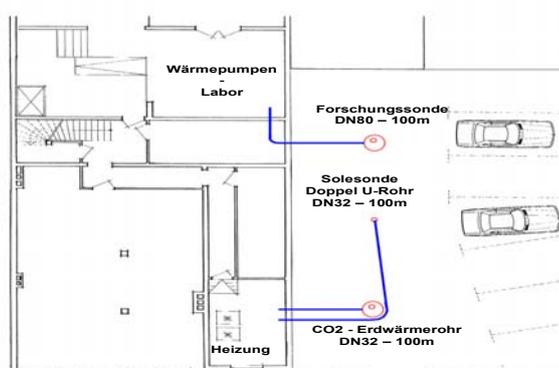


Figure 9: Map of the FKW- underground floor and the parking lot with the three earth probes and connecting pipes to the heating system and the heat pump laboratory

Here, three boreholes were drilled, each of 100 m depth, two with 160 mm diameter for a CO₂ earth pipe and a brine earth probe and another one with 180 mm for a 100 m larger stainless steel flexible pipe to be filled with water or brine in order to be able to insert into this pipe earth probes or heat pipes for further research or development investigations.

This research earth probe is located close to the wall of the heat pump laboratory inside the building and the other two earth probes close to the heating system room so that adequate connections are possible to the connected heat pumps and measuring devices. The drilling of these three boreholes had been performed between 23 and 27 of July, 2007, whereas the

further installations of the two first mentioned earth probes, a brine and a CO₂ earth probe, have been finished by the end of January, 2008. The research borehole will be taken into operation in spring 2008 for research work.

5 MARKET INTRODUCTION

After in 2006 the FKW-CO₂-earth heat pipe was covered by a patent No. DE10327602.5-15 FKW and Brugg convened a license agreement for manufacturing and marketing this novel type of CO₂ earth probes.

For the market introduction development work first had to be done for an industrial production of the heat pipe system with lower costs. This concerned mainly the heat exchanger on top of the heat pipe.

The first step for development was therefore to perform a new design and calculation for lay out of the heat exchanger area for various capacities according to different heat pipe length by applying computer calculations and tests at the FKW heat exchanger test rig.

The result of the development is shown in **Figure 10**, with the industrially manufactured heat exchanger system, without and with insulation, containing below the vessel the graphite sealing device, a bottom plate for fixing the system on the floor of an underground concrete containment for the heat pipe head.



Figure 10: a) Industrially manufactured HX with graphite sealing and foot b) New designed heat exchanger coil with graphite sealing and insulation

The graphite sealing system is in use for a lot of pipe connections in applications for gasoline stations working with hydrocarbon fuels and gases, where tightness is very important because of possible flammability.

After in 2007 some 10 newly designed Brugg-FKW-CO₂ Earth Heat pipes have been delivered it is planned to start further market introduction in 2008.

6 LITERATURE

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