SOLAR ASSISTED DISTRICT HEATING SYSTEM WITH DUCT HEAT STORE IN NECKARSULM-AMORBACH (GERMANY)

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Abstract – In Neckarsulm-Amorbach a solar assisted district heating system is being realised. The planned solar fraction based on the total heat demand (space heating and domestic hot water) is 50 %. To reach such high solar fractions seasonal heat storage is needed. Therefore a duct heat store was constructed. The storage temperature will be up to 80 °C. The duct heat store was extended in several phases according to the extension of the residential area. The residential area presently consists of 160 accommodation units and several public buildings. The duct heat store has a volume of 63,360 m³ heated-up by 5,007 m² solar thermal collectors. In 2002 a solar fraction of 39 % was reached. This value meets the expected solar fraction for the present stage of the solar assisted district heating system.

1. INTRODUCTION

Since 1997 the first solar assisted district heating system with duct heat store in Germany is being realised in Neckarsulm-Amorbach, located in the south-west of Germany.

With seasonal heat storage the seasonal discrepancy in heat delivery by solar thermal collectors and heat demand for space heating is balanced.

2. SYSTEM DESCRIPTION

The residential area presently consists of about 160 accommodation units in different kinds of buildings such as a multifamily residence, terraced houses and a retirement home. Furthermore a shopping centre and a school with gymnasium belong to the residential area, see figure 1. In the final stage the residential area will consist of approximately 1,300 accommodation units.

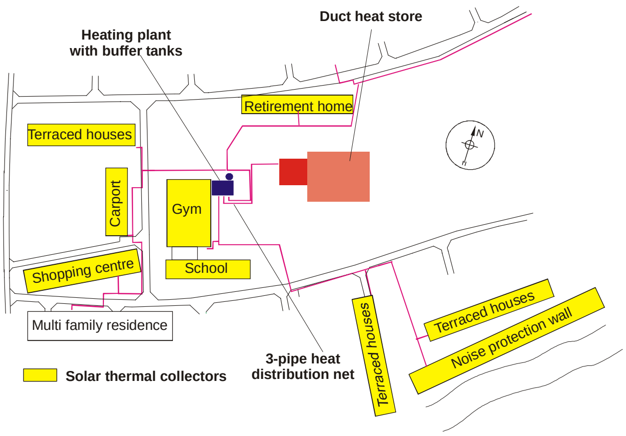

Fig. 1: Plan of the site in Neckarsulm

The solar thermal collectors with a total area of presently 5,007 m² are installed on different buildings as well as on a carport and a noise protection wall. For the second extension of the duct heat store the designed collector area is 5,500 m² for a planned solar fraction of 50 %. The duct heat store was extended in 2001 to a volume of 63,360 m³. 528 borehole heat exchangers (double-U-pipes) are installed to charge and discharge the duct heat store. In table 1 the data of the different phases of the extension of the duct heat store and the collector areas are listed.

Table 1: Extension phases of the heating system in Neckarsulm

Year	Volume of store in m³	No. of bore-hole heat exchangers	Solar collector area in m²	Designed collector area in m²
Experimental store 1997	4,320	36	-	-
1. extension 1998	20,160	168	2,640	2,700
2. extension 2001	63,360	528	5,007	5,500

In figure 2 the scheme of the solar assisted district heating system in Neckarsulm is shown. The duct heat store is directly connected to the heat distribution net and charged via buffer tanks by the solar collectors. The buffer tanks are used for short-term heat storage to balance peaks in heat delivery from the solar collectors.

The buildings are connected to the district heating system by a 3-pipe heat distribution net. The heat distribution net is supplied either by the buffer tanks or the duct heat store, depending on the temperature level. A gas condensing boiler supplies additional heat if none of the stores is able to deliver heat at the requested temperature level.

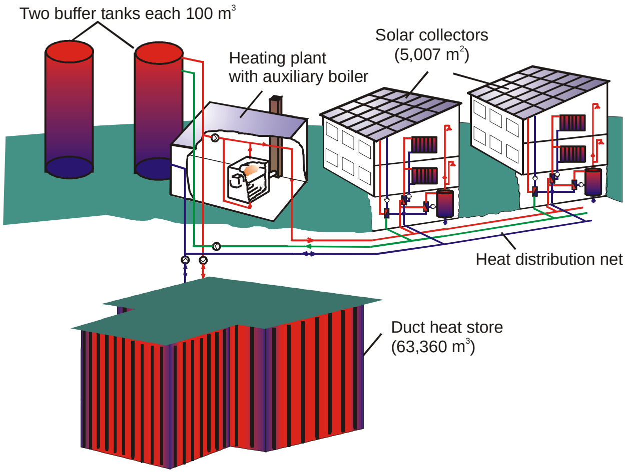

Fig. 2: Scheme of the solar assisted district heating system in Neckarsulm-Amorbach

3. DUCT HEAT STORE

As mentioned the duct heat store is used for seasonal heat storage. In summertime the heat delivery from the solar collectors which is not needed in the heat distribution net is delivered to the duct heat store. The heat is directly stored in the ground.

The duct heat store is charged and discharged by borehole heat exchangers. The borehole heat exchangers in Neckarsulm are double-U-pipes, see figure 3 and 4, which are made of polybutene [Nu]. Polybutene (PB) is the only material which guarantees a lifetime of at least 50 years at temperatures of 85 °C and pressures of 10 bar. The length of the U-pipes is 30 m, the outer diameter is 25 mm and the wall thickness is 2.3 mm. The boreholes are filled with a grouting material consisting of a suspension of bentonite, sand, cement and water to improve the heat transfer to and from the ground. The store is thermally insulated on top with a 200 mm layer of polystyrene to minimise heat losses. The store is covered by 2-3 m of soil.

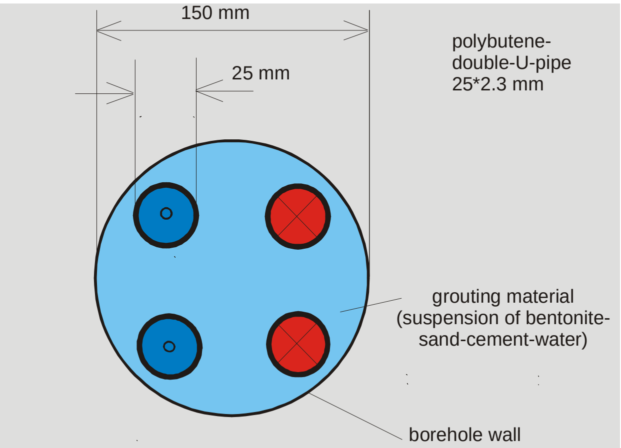

Fig. 3: Scheme of a borehole heat exchanger

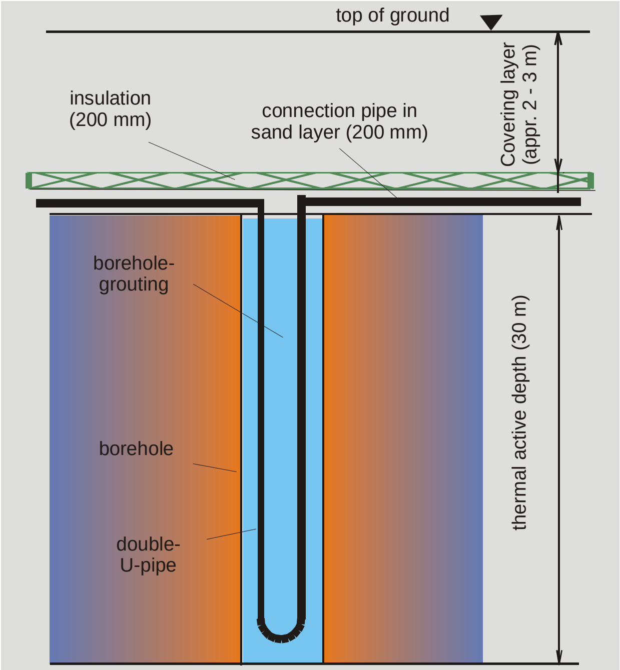

Fig. 4: Scheme of a borehole heat exchanger

The distances between two boreholes are 2 m in the experimental store and the first extension, see figure 5. In the second extension the distances between two boreholes are 1.5 m in the centre of the store and 2.5 m at the sides. With this construction heat losses at the sides are minimised.

Because high hydraulic conductivity in combination with ground water flow causes high heat losses a site with a low hydraulic conductivity and/or no ground water flow has to be preferred to locate the site for a duct heat store. For this reason in Neckarsulm only the first 30 – 35 metres below ground surface (gypsum rhaet-karn) can be used for heat storage. The hydraulic conductivity in this layer is very low ($k_F \approx 5 \cdot 10^{-8}$ m/s), whereas the hydraulic conductivity in the following dolomite layer is much higher ($k_F \approx 2 \cdot 10^{-5}$ m/s). The volumetric heat capacity of the duct heat store is 2.85 MJ/(m³·K), the thermal conductivity is 2.2 W/(m·K).

The duct heat store in Neckarsulm was built in three phases. The experimental store, see figure 5, was built to evaluate soil and store parameters which were used in system simulations. The first and second extensions were realised in 1998 and 2001 in accordance to the residential area. Presently 528 double-U-pipes are installed.

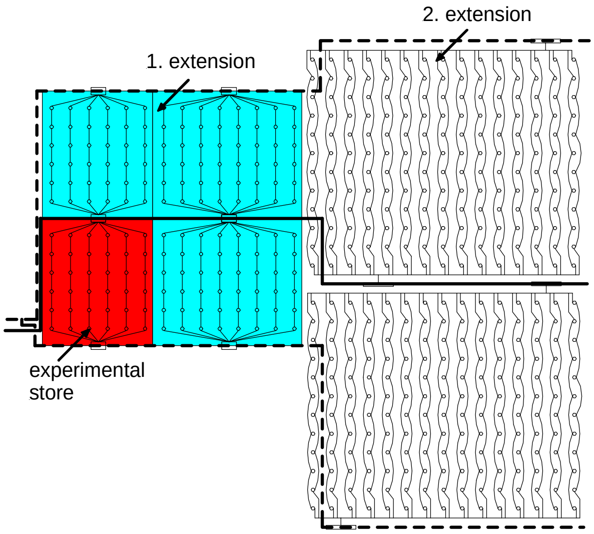

Fig. 5: Scheme of the duct heat store in Neckarsulm

Figure 6 shows the duct heat store under construction during the second extension. In difference to the construction of the experimental store in the first and second extension a drainage layer (gravel stones) was filled into the excavation. Thus the drilling was continued even during and after heavy rain falls. The construction period decreased compared to the experimental store.

Furthermore the installation of the 30 m long pipes was improved by installing the pipes with a crane.

Fig. 6: Duct heat store under construction (2. extension)

Duct heat stores are only on top insulated for constructive and economical reasons. The insulation of the experimental store and the first extension consists of a polyethylene (PE) layer, 200 mm polystyrene and a gravel layer in which surface water should have been drained. An excavated sample from the first extension showed a permanent moisture penetration of the polystyrene layer. Measurements indicate that the moisture penetration results in increased heat conductivity in comparison to dry polystyrene. Therefore in the second extension a construction of the insulation, see figure 7, was realised which guarantees high insulation effects for a long time.

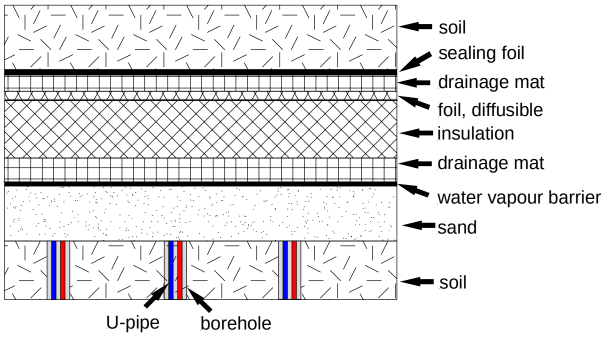

Fig. 7: Construction of the insulation in the 2. extension

4. SOLAR COLLECTORS

In Neckarsulm different kinds of installation of solar collectors are realised. The solar collectors on the carport, the shopping centre, the noise protection wall and the gymnasium (figure 8) are mounted on a sub construction whereas the solar collectors on the terraced houses (figure 9), the retirement home and the school are roof integrated.

Fig. 8: Solar collectors on the gymnasium

Fig. 9: Solar collectors on the terraced houses

5. 3-PIPE HEAT DISTRIBUTION NET

In Neckarsulm a 3-pipe heat distribution net was installed which consists of two supply pipes (distribution net and collector) and only one return pipe for both, distribution net and collector, see figure 10. The collector return temperature is a mixture of the distribution net return temperature and the temperature of the return pipe from the heating plant which is supplied by the buffer tanks or the duct heat store.

The 3-pipe heat distribution net was installed since it was expected to be easier extendable and to be cheaper than a 4-pipe heat distribution net because one pipe is saved. But the therefore necessary special heat transfer stations were expensive. Finally no cost reduction was reached.

In the 3-pipe heat distribution net no pipes with water-glycol-mixture are in the ground since all heat transfer stations are in the buildings on which the collectors are installed or close to the collector fields. Therefore less glycol which is used as an antifreeze agent is needed. Another advantage of the 3-pipe net is the possibility of installing collector fields with very different orientations and tilt angels since each collector field can be controlled separately.

The major problem of the 3-pipe heat distribution net is the difficulty in monitoring and controlling. Operational failures are difficult to detect.

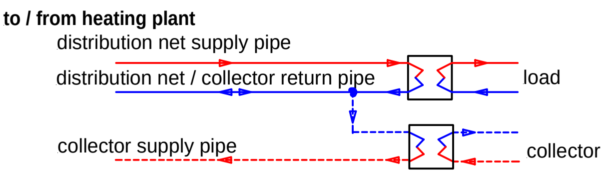

Fig. 10: Scheme of a 3-pipe heat distribution net

6. RESULTS AND EXPERIENCES

6.1 Duct heat store

The temperatures in different depths measured in the middle of the first and second extension of the duct heat store are shown in figure 11 and 12. The highest measured temperature was 57 °C (depth 20 m) in the middle of the first extension in 2000. The experimental store and the first extension were not charged in 2002. With this strategy a fast temperature adaptation of the different duct store parts can be reached.

The temperature above the thermal insulation (-0.2 m) is not only dependent on charging periods but also follows the ambient air temperature.

The temperature below the thermal insulation (0 m, this means 3 m below ground surface) in the first extension (figure 11) is about 15 K lower than above the insulation. But the insulation effect decreased due to increasing moisture content in the insulation material.

The temperature 2 m below the store (32 m) increased in the first extension 15 to 20 K in comparison to undisturbed ground temperature due to heat losses. Heat losses of duct heat stores are high in comparison to other types of stores since duct heat stores can only be insulated on top of the store.

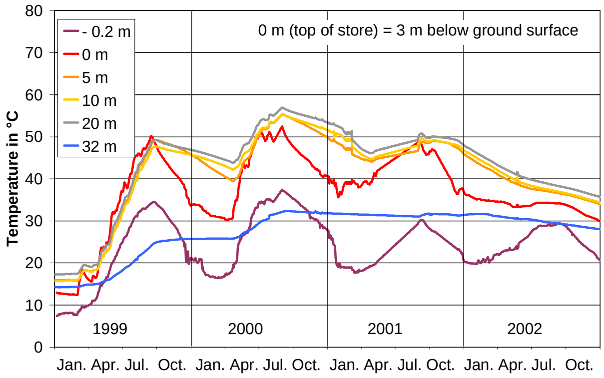

Fig. 11: Temperatures in the middle of the first extension of the duct heat store in Neckarsulm

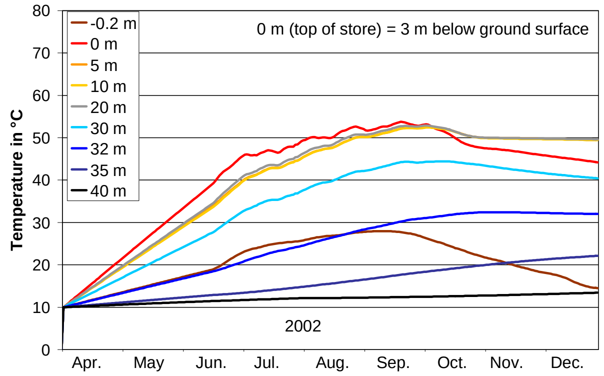

Fig. 12: Temperatures in the middle of the second extension of the duct heat store in Neckarsulm

6.2 Solar collectors

Figure 13 shows the daily gross heat gain of the solar collectors versus the daily hemispherical solar radiation in 2002. The hemispherical solar radiation was measured with a tilt angle of 15 ° and an azimuth of –20 °. It is evident that the solar collector fields are rarely in stagnation or due to a failure out of operation; some cases of stagnation or failure are labelled with date.

Furthermore it is to be seen in figure 13, that especially at high hemispherical solar radiation the heat gain of the collector field „shopping centre" is much lower than the heat gain of other collector fields. This is due to high distribution net return temperatures of the shopping centre. The heat gain of the collector field „noise protection wall" is in difference to the other collector fields usually higher at same radiation values. The reasons are a low collector return temperature which is supplied by the cold duct heat store and a higher tilt angle (33 °) in comparison to the other collector fields (15 - 20 °).

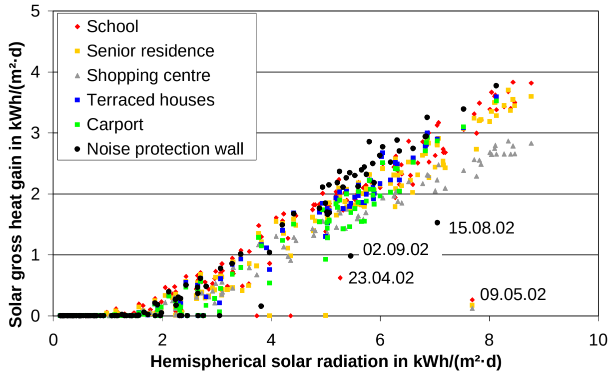

Fig. 13: Gross heat gain of solar collectors versus hemispherical solar radiation for the year 2002

In figure 14 the solar gross heat gains of the collector fields in the years 1999 - 2002 are compared. It is to be seen that the solar heat gain varies during the years.

In **2000** the control unit failed and the collectors were operated manually for several months. In addition the second buffer tank was installed which caused service interruption. Furthermore some components such as a heat exchanger and a pump failed which was not immediately detected.

In **2001** the duct heat store was extended and therefore no heat storage was possible during the summer. Since the heat demand in the heat distribution net is in summer much less than the heat delivery from the solar collectors some collector fields were manually taken out of operation or in stagnation.

In **2002** the solar heat gains reached the highest values of all years. This is the result of only minor operational and technical problems and of course of low return temperatures (to the collectors) since the duct heat store started to be heated-up from just ~ 10 °C.

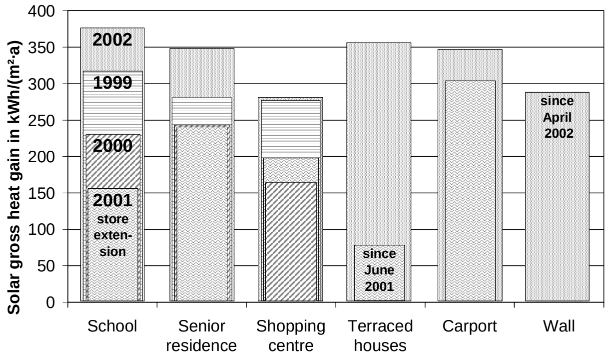

Fig. 14: Comparison of solar gross heat gain of different collector fields in the years 1999 to 2002

6.3 Heat balances

In table 2 the most important data of the heat balances for the years 1999, 2000 and 2002 for the district heating system in Neckarsulm are listed [SUN].

The collector area was extended from 2,636 m² in 1999 to 5,007 m² in 2002. The solar heat delivery to the heat distribution net consists of the direct use of solar heat and of the solar heat which is discharged from the duct heat store.

The total heat delivery to the heat distribution net consists of the solar heat delivery and the heat delivery by the gas boiler. The total heat demand increased due to extension of the residential area.

The heat losses of the heat distribution net are very high (about 30 %) since the net is almost completely installed while only a few buildings are connected.

The solar fraction -based on the total heat demand- increased from 18 % in 1999 to 39 % in 2002. It is expected that the planned solar fraction (50 %) will be reached as planned in a few years.

Table 2: Data of the heat balances in Neckarsulm

		1999	**2000**	**2002**
Collector area	m²	2636	3090	5007
Heat delivery of solar collectors	MWh/a	802	577	1696
per m²	kWh/m²	304	219	331
Solar heat delivery to heat distribution net	MWh/a	250	213	822
per m²	kWh/(m²·a)	95	81	164
Total heat delivery to heat distribution net	MWh/a	1241	1247	1720
Heat losses in net (calculated)	MWh/a	349	242	533
Heat delivery by gas boiler	MWh/a	1028	1034	1303
Solar fraction (based on total heat demand)	**%**	**18**	**17**	**39**

6.4 Distribution net return temperature

The distribution net return temperature decreased from 47.6 °C in 1999 to 43.3 °C in 2002 mainly due to decreased distribution net supply temperatures. The effect on the system behaviour is shown in figure 15 [Sei]. It is seen that a decreasing net return temperature causes an increasing storage efficiency and solar fraction.

It is also evident that a duct heat store needs 5 - 8 years of operation until steady state conditions are reached. This is caused by a long heating-up period of the store.

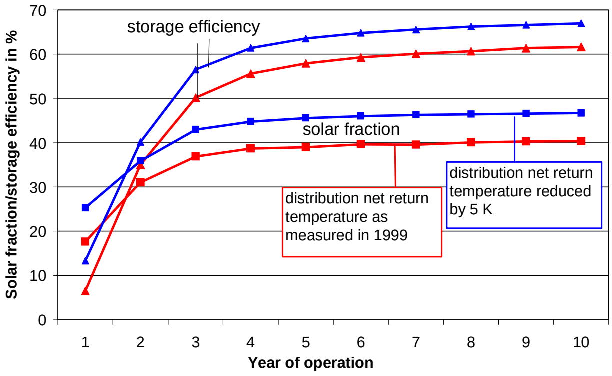

Fig. 15: Solar fraction and storage efficiency versus year of operation [Sei]

7. OUTLOOK

A further extension of the duct heat store is planned when the heat demand in the residential area increases. However instead of extending the duct heat store, the installation of a heat pump will be taken into consideration to increase the usable temperature level of the duct heat store.

REFERENCES

[Sei]
Seiwald, H. and Hahne, E. (2000) Underground seasonal storage for a solar heating system in Neckarsulm / Germany. Proceedings of Terrastock 2000, 28.08.-01.09., Stuttgart, Germany, Benner, M. and Hahne, E. (eds.), pp. 213-219

[Nu]
Nußbicker, J.; Mangold, D.; Heidemann, W.; Müller-Steinhagen, H. (2002) Erfahrungen aus Betrieb und Ausbau der solar unterstützten Nahwärmeversorgung mit Erdsonden-Wärmespeicher in Neckarsulm-Amorbach. Tagungsband 12. Symposium Thermische Solarenergie, 24.-26.04.2002, Staffelstein, Germany, pp. 471-475

[SUN]
Mangold, D.; Nußbicker, J.; Raab, S.; Schmidt, Th.; Müller-Steinhagen, H. (2003) Solar unterstützte Nahwärmeversorgung mit und ohne Langzeitwärmespeicher, Forschungsbericht zum BMWi-Vorhaben 0329606S, ITW Universität Stuttgart

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