Integration of Solar Thermal Systems into Gas Pressure Regulating Stations

Roland Heinzen[1], Katrin Zaß[2], Raban Luhmer[3], Ralf Meyer[3], and Klaus Vajen[2]

[1] FSAVE Solartechnik GmbH, Kassel (Germany)

[2] Kassel University, Institute for Thermal Engineering, Kassel (Germany)

[3] E.ON Mitte AG, Kassel (Germany)

1. Abstract

Within this paper the possibility to use solar thermal energy for the preheating of gas in gas pressure regulating stations is investigated. First the operating principle and the technical characteristics of gas pressure regulating stations are described and different options to integrate a solar thermal system are discussed. Then the plans for the realization of a pilot plant are presented. Annual system simulations are performed to identify the optimal dimensions and operation parameters for the pilot plant. Finally, it is concluded that in gas pressure regulating stations ideal conditions can be found for an economically competitive use of solar thermal energy.

2. Introduction

Gas pressure regulating stations are used to reduce the pressure of natural gas in long distance grids to the consumer level. Gas pressure regulating stations are to be found distributed all over Germany. The pressure reduction is endothermic, i.e. the addition of heat is required to avoid the freezing of system components and to guarantee the security of gas supply. For the preheating of the natural gas conventional gas burners are used. Due to the unbundling law, the operators of natural gas grids in the EU have to pay market-based prices for their own gas consumption. This premise as well as the profile of the heat demand of gas pressure regulating stations pose ideal conditions for the economically competitive use of solar thermal energy for preheating of gas.

However, grid operators hesitate to invest in such rather new and therefore insecure technologies like solar thermal systems. By law the apportionment of their additional invest in new technologies is not granted. That is why within this project a new approach, the solar thermal heat contracting, is investigated to nevertheless make the use of solar thermal energy possible. Within the frame of a development project, a consortium of three industry partners and Kassel University work on the elaboration of a contracting model and the realization of a pilot plant since September 2010. This paper focuses on the technical aspects of the project. It gives a description of the technical characteristics of gas pressure regulating stations and presents the investigations made for the realization of a pilot plant. These investigations comprise reflections on different options for the hydraulic integration as well as system simulations (TRNSYS) that are carried out to investigate how the specific collector area and specific heat store volume influence the amount of heat that is delivered to the system. More information on solar thermal heat contracting and its regulatory boundary conditions in Germany can be found in (Schaede, 2011).

3. Technical Characteristics of Gas Pressure Regulating Stations

Gas pressure regulating stations reduce the pressure of natural gas from about 80 to100 bar in the long distance grids to about 16 bar in the district distribution grids. The pressure reduction by a throttle valve forces the Joule-Thomson effect, which causes a temperature decrease of the gas of up to 25 K. Therefore, the components behind the throttling valve suffer by the risk of freezing, which could cause corrosion and material defect in this very safety sensitive application. Hence, the gas is preheated before the throttling process. This is usually done by a gas burner and a heating cycle. Preheating of the natural gas usually consumes 0.2 % of the natural gas calorific value. This can result to an annual heating demand of a large station of about 0.5 to 4 GWh/a. Yet, the rather low needed temperature level of only about 20 to 40°C in the natural gas before the pressure reduction and the almost constant annual heat demand for large gas pressure regulating stations present ideal conditions for the use of regenerative heat sources like solar thermal systems.

Fig. 1 shows the monthly cumulated gas mass flow through an exemplary gas pressure regulating station for the years 2008 and 2009, respectively. It has an annual heat demand of about 1.7 GWh/a . Although there is a maximum in winter, the summer gas demand decreases only by 40 to 50% compared to the winter demand. This is caused by a large share of industrial customers in many large gas pressure regulating stations, which have an almost constant gas demand throughout the year.

The high summer gas demand is one of the reasons why this respective station was selected for the installation of the pilot plant. Other reasons were the availability of sufficient area for the installation of the collectors on building roofs or in open space and its topography and current usage.

In the selected station the gas is reduced from 90 bar at 7° C to 16 bar at 10° C, the gas before the throttling process thus needs to have a temperature of about 40° C.

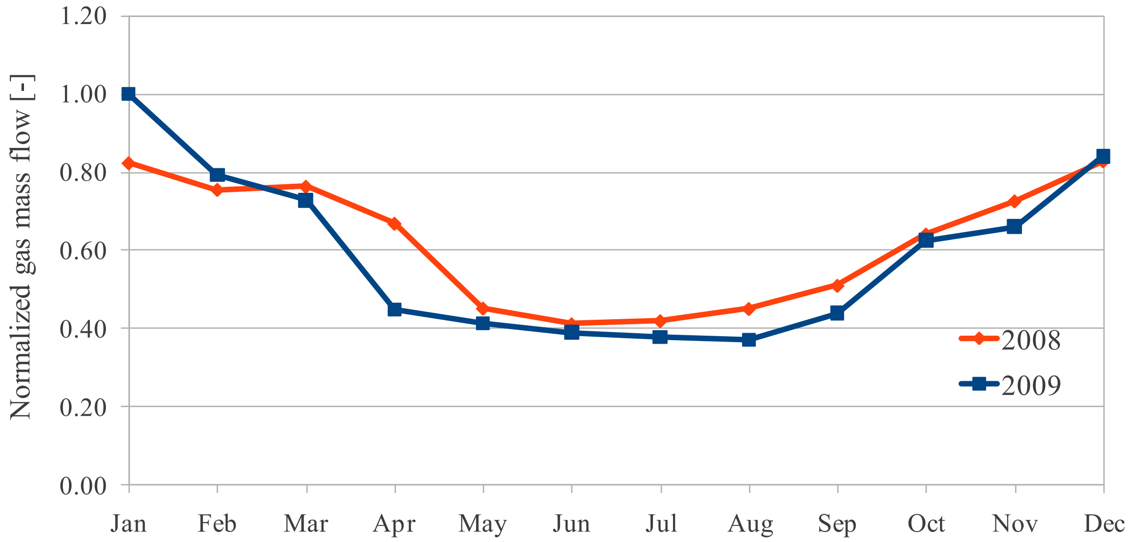

Fig. 1: Normalized monthly gas mass flow profile for 2008 and 2009 for an exemplary large gas pressure regulating station.

4. Realization of the Pilot Plant

In a first step it had to be determined how and where the solar thermal system can be integrated into the gas pressure regulating station. Then annual system simulations were performed to identify the optimal dimensions and operating parameters for the solar thermal system.

4.1. Integration of the Solar Thermal System into the Gas Pressure Regulating Station

The upper part of fig. 2 shows the hydraulic scheme of the gas pressure regulating station where the pilot plant will be installed.

The most efficient way for the integration of a solar thermal system would be to install an additional heat exchanger in the gas inlet flow and directly preheat the gas with solar energy. At the heat exchanger inlet the gas has a constant temperature of only 7°C. However this option would require construction works in an area with potentially explosive atmosphere. Due to the high safety requirements for components and works in this area this option would be too expensive.

Instead, the solar thermal system will be installed in the return flow of the existing heating system of the station, as shown in the lower part of fig. 2. The disadvantage of this option is the high return flow temperature of about 42°C from the gas to water heat exchanger. This is because the heat exchanger is operated with co-current flow. The influence of the return flow temperature on the yield of the solar thermal system is discussed in the next chapter.

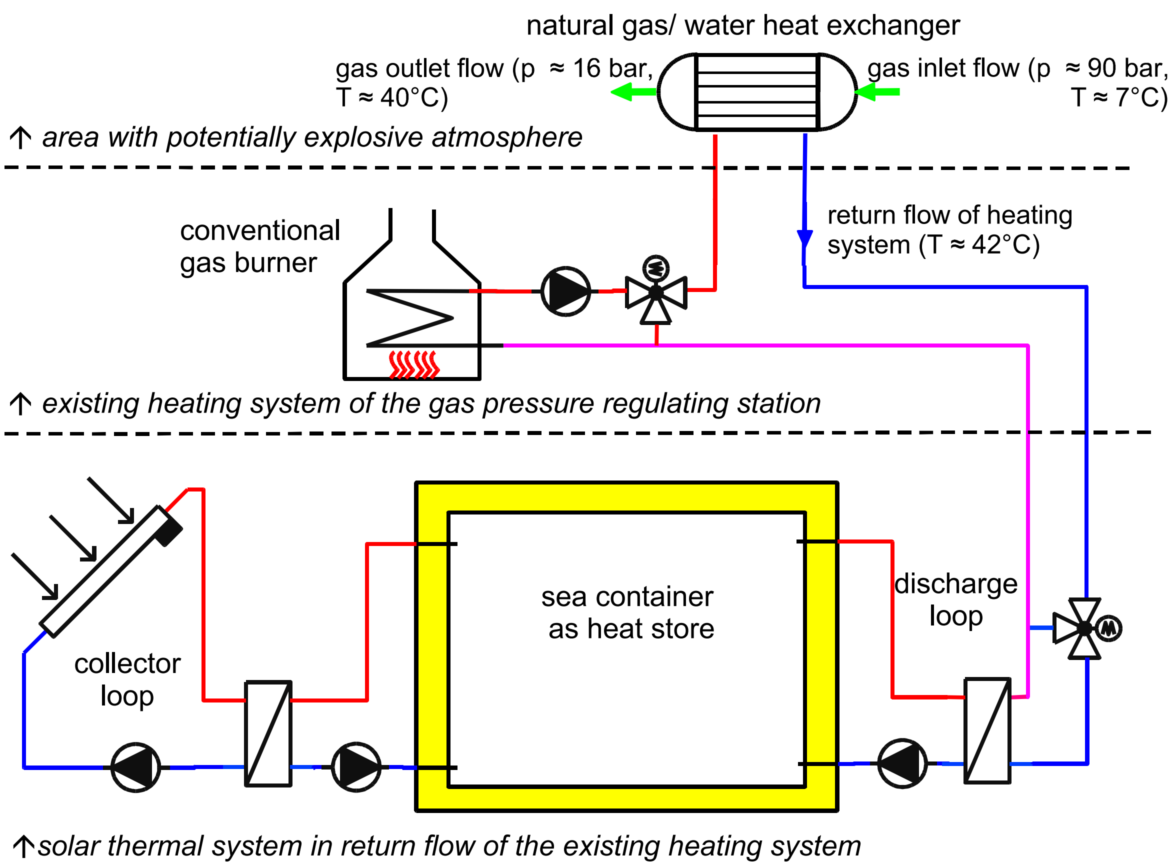

Fig. 2: Hydraulic scheme of the gas pressure regulating station and the planned integration of the solar thermal system.

4.2. System Simulations

For the hydraulic integration of the solar thermal system as shown in fig. 2 annual system simulations were performed with the aid of the simulation program TRNSYS 16.1 (Klein et al, 2006). The aim of the simulations was to identify the optimal dimension of the main components collector and heat store. Also, the influence of the return flow temperature and the use of different types of collectors on the solar thermal system yield was investigated. In tab. 1 the boundary conditions for the simulations are summarized. The measured gas flow rate of 2009 was used as load profile for the investigation.

Tab. 1: Boundary conditions for the simulations with TRNSYS 16.1:

Weather data	Gießen (location of the nearest weather station)
Simulation time step	0.05 h
Load profile	Measured load profile of the gas pressure regulating station from 2009, hourly values
Gas burner	500 kW, eta 85 %
UA-value of charge and discharge heat exchanger	140.000 W/K
Azimuth angle	0°/South
Collector slope	35°
Specific mass flow in collector loop	17 kg/m²h

The system components shall be dimensioned according to the lowest summer load, i.e. the solar energy shall always be directly used. The heat store is only used to buffer daily load peaks and to store the energy for the night.

4.3. Influence of the Return Flow Temperature on Solar Thermal Energy Yield

For the pilot plant a rather constant return flow temperature of the heating system of about 42°C was measured. As mentioned before this is because the gas to water heat exchanger is operated in co-current flow, which is the case in most gas pressure regulating stations. Fig. 3 shows the influence of the return flow temperature on the amount of solar heat that can be delivered to the gas station for a reference case with a heat store volume of 25 m³ and a collector area of 500 m² (flat plate collector). As expected, the return flow temperature has a large influence on the solar thermal system yield and thus on the economic viability of the system. By reducing the return flow temperature from 42° C to 26° C the specific yield increases from 420 to 550 kWh/m²a.

It can be concluded that the return flow temperature is a decisive parameter for the eligibility of a gas pressure regulating station for the integration of a solar thermal system.

In case of the station where the pilot plant will be installed reconstruction works in the existing heating system made it possible to change the flow regime of the heat exchanger without additional costs. With this modification a return flow temperature of about 26° C can now be expected.

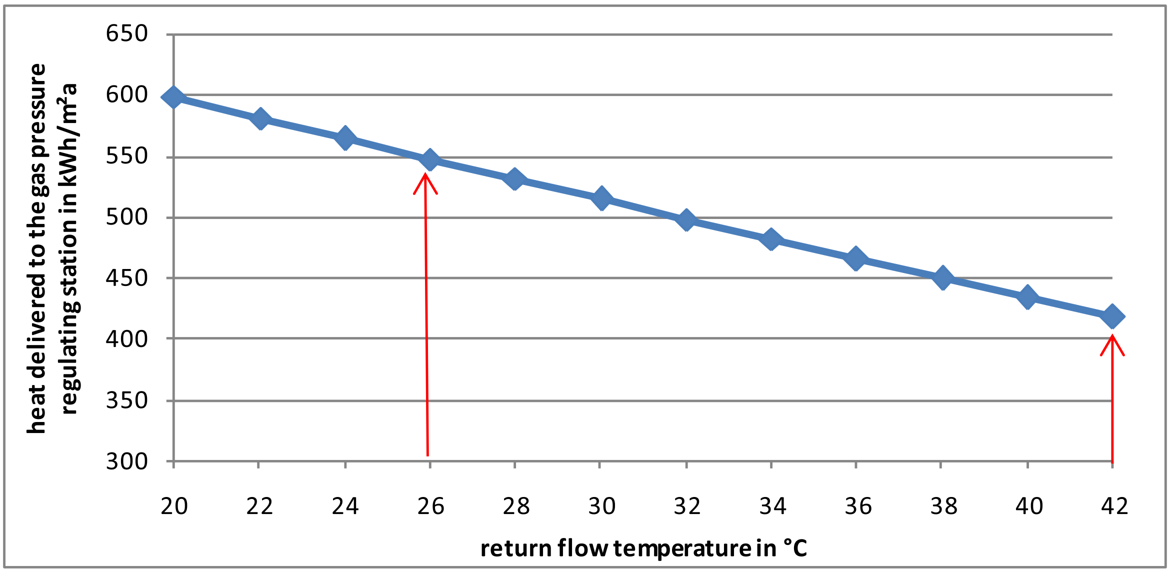

Fig. 3: Influence of return temperature on specific solar thermal system yield

4.4. Influence of Collector Type and Area on Solar Thermal Energy Yield

Fig. 4 shows the amount of heat that is delivered to the gas pressure regulating station per m² collector area for different collector types. The simulations were performed with a specific store volume of 75 l/m² collector area and an average return flow temperature of 26°C and 42°C. The thermal performance values for the different collector types are taken from the respective test reports according to DIN EN 12975-2:2006. The given collector area in Fig. 4 is the aperture area.

The comparison shows large differences in the performance of the various collector types. As expected, the highest energy yields are achieved with vacuum tube collectors. They yield up to 30% (200 kWh) more than the large scale flat plate collector. Disappointing is the result for the low cost vacuum tube collector that lies well below the performance of the flat plate collector.

The results also show that the influence of the return flow temperature is higher for the flat plate collector than for the vacuum tube collectors. This is due to the typically better heat insulation of vacuum tubes. For gas pressure regulating stations where high return flow temperatures have to be expected the use of vacuum tube collectors therefore should be considered. For this pilot plant, where a return flow temperature of 26°C is expected, it was decided to install the large scale flat plate collector. Despite the higher specific energy yields of the vacuum tube collectors, the flat plat collector resulted to be more cost effective under these circumstances.

Other than the collector type, the variation of the collector area has only a small influence on the specific yield. Since the specific costs per installed m² are more or less constant for large collector areas of more than 100 m² the collector area itself thus has no influence on the economic viability of the system. Therefore other criteria like the available area or the available capital have to be considered to decide on the dimensioning of the collector area.

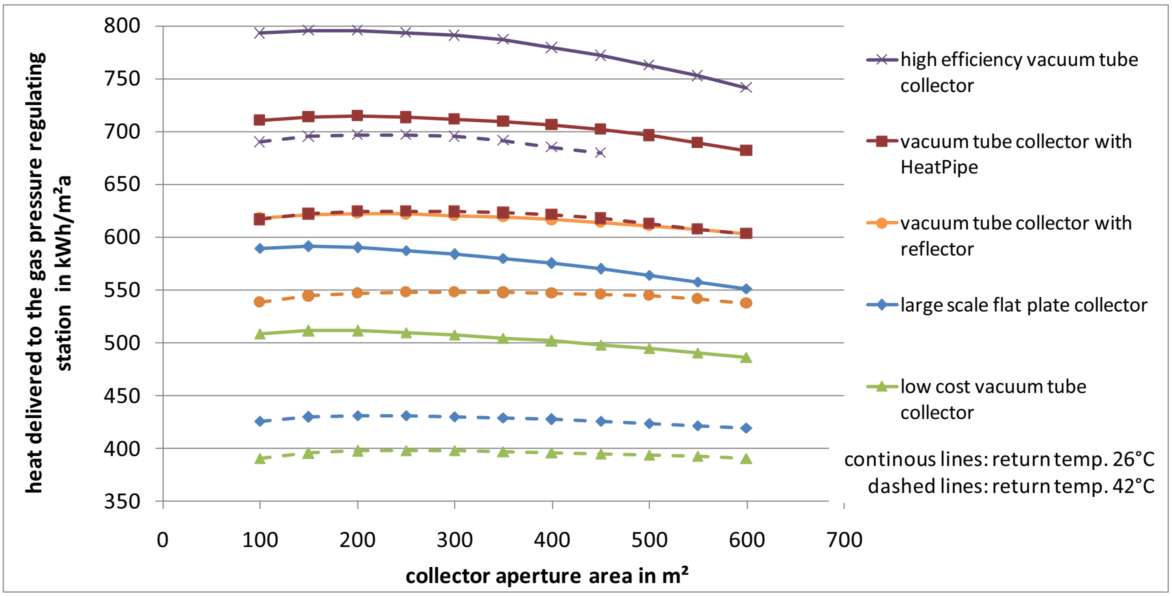

Fig. 4: Influence of collector type and collector area on specific solar thermal system yield (heat delivered to the gas pressure regulating station)

4.5. Volume of the Heat Store

As heat store a customized 20 feet marine container is used (see Fig. 5). To make the container useable as hot water store the walls are reinforced with a steel construction and a heat insulation made of polyurethane-foam is introduced. A casing of polypropylene sheets makes the store watertight. One container can keep a water volume of 25 m³.

Fig. 5: Customized 20 feet marine container that serves as heat store.

Fig. 6 shows the amount of heat that is delivered to the gas pressure regulating station with different heat store volumes. The specific volume per m² collector area was varied from 0.045 m³/m² to 0.12 m³/m² at a collector area of 300 and 500 m². As for the specific collector area, the variation of the specific store volume has only a small influence on the specific yield. Thus for the pilot plant one container heat store with a volume of 25 m³ will be installed.

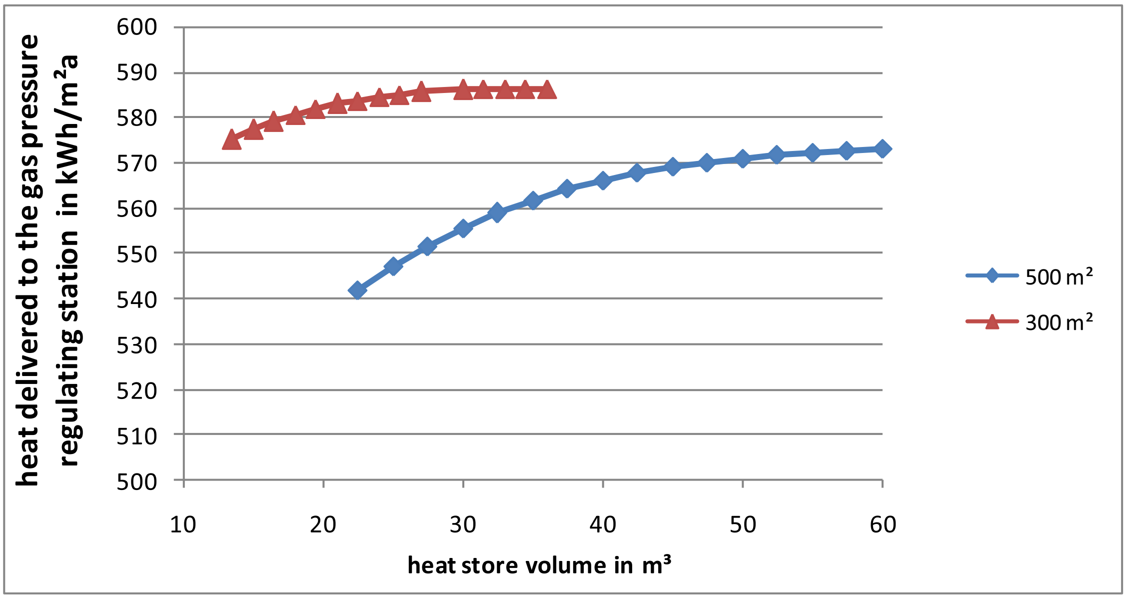

Figure 6: Influence of the specific heat store volume on the specific solar thermal system yield (heat delivered to the gas pressure regulating station)

5. Discussion & Outlook

In this paper, the use of solar thermal energy for the preheating of gas in gas pressure regulating stations was investigated from the technical point of view. As a first result it can be stated that the technical characteristics of large gas pressure regulating stations are ideal for the integration of alternative energy sources. That is due to a rather constant annual heat demand profile and the low required set temperatures for the preheated gas.

In a next step, different options for the hydraulic integration of solar thermal systems into gas pressure regulating station were considered. The conclusion here is that due to safety reasons the option to directly preheat the gas with solar energy is too expensive. The remaining option is the installation of the solar thermal system in the return flow of the existing heating system.

Finally, the first planning steps towards the realization of a pilot were presented. Annual system simulations were performed with the aid of the simulation program TRNSYS.

The results can be summarized as follows:

- The return flow temperature from the gas to water heat exchanger was identified as an important factor for the economic competitiveness of solar thermal energy in gas pressure regulating station.
- The influence of the return flow temperature is higher for the investigated flat plate collector than for the vacuum tube collectors. The choice of the most appropriate collector type thus depends on the return flow temperature that has to be expected in a gas pressure regulating station.
- In contrast to that the dimensioning of the solar thermal system components (collector area and heat store volume) showed to have only a small influence on the specific yield and thus on the economic viability.

Until spring 2012 the solar thermal pilot plant will be erected and ready for operation. The system will be equipped with a detailed monitoring system, which will allow to proof the system design.

6. Acknowledgements

The authors acknowledge the support by ”*Hessen Modellprojekte*“, which is funded by *”LOEWE - Landesoffensive zur Entwicklung Wissenschaftlich-ökonomischer Exzellenz, Förderlinie 3: KMU-Verbundvorhaben“, (HA-Projekt-Nr.: 238/10-14).*

7. References

DIN EN 12975-2: Thermische Solaranlagen und ihre Bauteile – Kollektoren – Teil 2: Prüfverfahren; Deutsche Fassung, EN 12975-2:2006

Klein, S.A., Beckman, W.A., Mitchell, J.W., Duffie, J.A., Duffie, N.A., Freeman, T.L. et al, 2006. A Transient System Simulation Program, the Solar Energy Laboratory, University of Wisconsin-Madison, Madison

Schaede, M., 2011. Anwendung des Wärme-Contractings auf die solarthermische Beheizung von Gasdruckregelanlagen, Fachbereich Maschinenbau, Institut für Thermische Energietechnik, Universität Kassel