OPERATING EXPERIENCE OF A SOLAR DRIVEN 10 KWc AMMONIA/WATER ABSORPTION CHILLER IN A MODERN WINERY

Marko Zeiler[1], **Reinhard Padinger**[2] and **Stefan Gunczy**[3]

1 JOANNEUM RESEARCH, Elisabethstraße 5, A-8010 Graz, Tel: +43 316 876 1334, Fax: +43 316 876 1320 marko.zeiler@joanneum.at

2 JOANNEUM RESEARCH, Elisabethstraße 5, A-8010 Graz, Tel: +43 316 876 1333, Fax: +43 316 876 1320 reinhard.padinger@joanneum.at

3 JOANNEUM RESEARCH, Elisabethstraße 5, A-8010 Graz, Tel: +43 316 876 1318, Fax: +43 316 876 1320 stefan.gunczy@joanneum.at

Abstract

Within the EU Project PolySMART (http://www.polysmart.org) a solar driven 10 kW_{cold} ammonia/water absorption chiller prototype has been coupled with a biomass driven 3 $kW_{electric}$ Stirling engine prototype at a modern winery in southern Styria. The solar driven absorption chiller has been operating for 6 years with only minor maintenance efforts at the beginning of the operation period. Constant improvements and optimization works let to the development of a market mature serial product, the PinkChiller PC19. Finally a measuring period of 12 months ended in November 2009. The results of this measuring period are presented in the paper at hand. Within the monitoring period the ammonia/water absorption chiller operated fully automatic without any maintenance requirements. For the Stirling engine a fully automatic control system was developed and implemented but the engine was not operated without human supervision because security issues occurred with very hot parts of the flue gas flaps and piping system.

1. Introduction

To meet the requirements of a modern winery, which produces high quality wine, refrigeration is needed for the cooling and dehumidification of the wine bottle storage, for the controlling of the fermentation process, for cooling of the mash and for the tartar (wine crystal) stabilization.

The evaporation temperatures for these processes are as follows:

- Cooling and dehumidification of the wine bottle storage, 0 to 3 °C.
- Controlling of the fermentation process, 0 to 5 °C.
- Cooling of the mash, 0 to 5 °C.
- Tartar stabilization, - 10 to - 15 °C.

So the ammonia-water based absorption refrigeration process is suitable for these applications.

2. System design

2.1. Installation characteristics

The installation is located at a winery in Southern Styria, Austria. There quality wine is produced. Heat, Cold and power are used in the following quantities:

- Heating capacity of about 50 kW (technical area and living area)
- Cooling capacity of 10 kW for the winery

- Electricity capacity of averaging 0,6 kW (in the technical area)

Thermally Driven Cooling TDC technology: solar driven 10 kW_{cold} ammonia/water absorption refrigeration chiller

Combined Heat and Power CHP technology: Woodchip fired 3 $kW_{electric}$ Stirling engine prototype

2.2 Hydraulic scheme

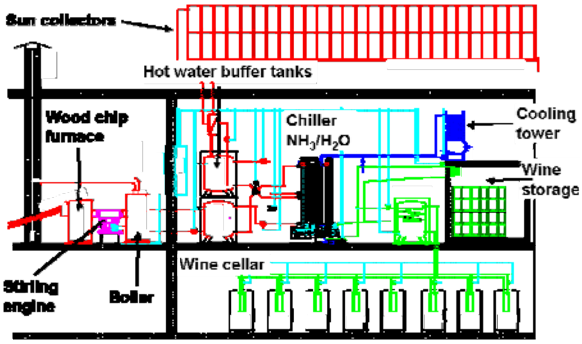

Fig. 1. Scheme of the CHCP (combined heat cold and power) system at the winery “Peitler”

Figure 1 shows the wood chip furnace, which produces the hot flue gas for the Stirling engine on the left side. After passing the heat exchanger of the Stirling engine, the hot flue gas heats up the boiler. Hot water from the boiler is stored in the hot water buffer tanks, together with the hot water from the solar collector system. From there the heating loops and the ammonia/water chiller are served. The cold is used to cool and dehumidify the wine bottle storage and additionally to control the fermentation process of the wine. The heat rejection system features a wet cooling tower with a capacity of 50 kW.

Technical data of the components are:

Solar collector field: 100.8 m^2, Cooling capacity: 10 kW_c, Heat capacity of the wood chip furnace: 50 kW_{th}, Power capacity of the Stirling engine: 3 kW_{el}, Buffer storage volume: 4,8 m^3.

2.3. Ammonia – water absorption refrigeration machine, TDC (thermally driven cooling)

The 10 kW_{cold} TDC was designed and constructed to meet the specific needs of a Styrian winery to demonstrate the environmentally friendly refrigeration from solar radiation and solid biomass. Due to constricted space in the technical area the components of the chiller were mounted on the wall of the technical room and they have been connected with stainless steel pipes. Further improvements on the technology throughout the project let to the development of the PinkChiller PC19 chiller, a serial product, which can be purchased on the market.

2.4. Stirling engine

The 3 $kW_{electric}$ alpha-type Stirling engine is constructed on the basis of an industrial motorcycle crank mechanism. The pistons of the original engine are used as crossheads for the Stirling pistons, which are built on top. It features a special heat exchanger design with smooth pipes aligned in flue gas direction in order to achieve a self cleaning effect. Within the project a fully automatic control strategy for the Stirling engine was developed and implemented. However no stand alone operation of the Stirling engine was carried out due to security concerns due to very hot parts of the flue gas flaps and piping system.

3. Results

3.1. General results

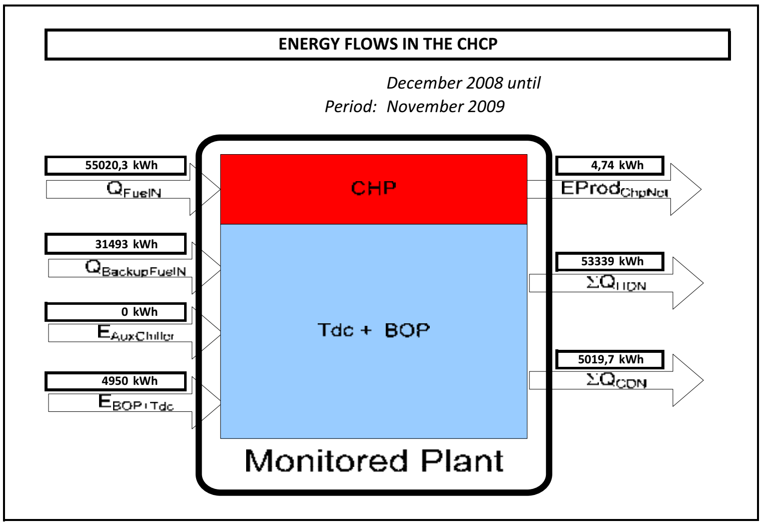

Fig. 2. Energy balance of the PolySMART installation

Figure 2 shows the energy balance of the PolySMART installation over the measuring period of one year. The measuring period was from December 2008 to November 2009. Q_{FuelIn} represents the wood chip input in kWh. $Q_{BackupFuelIn}$ is the solar heat input and $E_{BOP+Tdc}$ represents the electrical input over the measuring period. $EProd_{ChpNet}$ is the electricity output of the Stirling engine. Q_{HDN} is the heat distributed to the heat loads whereas Q_{CDN} represents the cold which was used in the system. It is seen that only a very small amount of electricity was produced over the evaluation period. The reason therefore is that the Stirling operation was limited to test runs in order to develop and implement the control strategy for the automatic operation. In addition it was seen that security issues did not allow stand alone operation because of very hot parts of the flue gas flaps and piping system.

3.1. Chiller

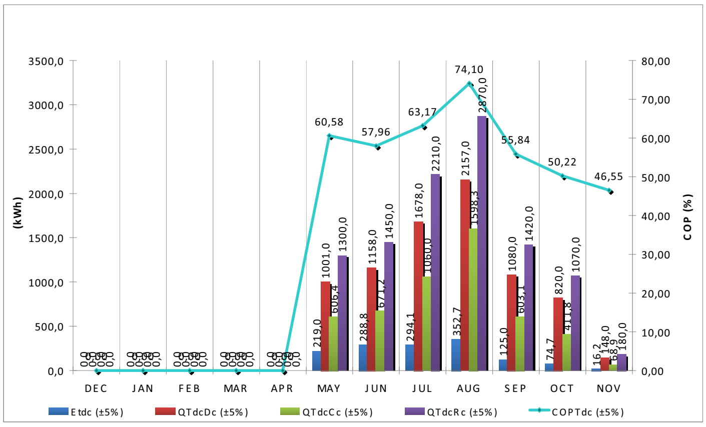

Fig. 3. Chiller energy balance and COP (Coefficient Of Performance)

Figure 3 shows the energy balance and the thermal COP (Coefficient Of Performance) of the ammonia/water absorption refrigeration chiller (TDC – Thermally Driven Cooling) over the evaluation period.

From May to September the chiller is operated to cool and dehumidify the wine bottle storage. In October it is used for the cooling of the mash and for the control of the fermentation process of the wine. Throughout the measuring period the driving heat was provided by the solar collector system. The desired COP of 74 % is reached in August, where the chiller operated at its designed parameters.

Etdc – electrical energy consumption of the solution pump of the chiller

QTdcDc – heat provided in the driving circuit of the TDC

QTdcCc – cold produced of the TDC

QTdcRc – heat rejected in the wet cooling tower (recooling)

COPTdc – thermal coefficient of performance

The absorption refrigeration machine was operated for 1951 hours from May until November 2009.

3.2. Electrical COP

Two electrical COPs (Coefficient Of Performance) for the cooling system have been evaluated:

1) $COP_{el,TDC}$ is calculated as the produced cold (Q_{TdcCc}) divided by the sum of the electricity used in the TDC (E_{Tdc}), the 3 connected hydraulic circles (E_{WP3}, E_{WP4}, E_{WP9}) and the direct evaporation fan (EM405) for the bottle storage cooling, over the whole operating period.

$$COP_{el,TDC} = \frac{Q_{TdcCc}}{E_{Tdc} + E_{WP3} + E_{WP4} + E_{WP9} + EM405} = \frac{5019.7kWh}{825.5kWh} = 6.1$$

2) $COP_{el,sys}$ includes the electric requirements for the TDC, the three hydraulic circuits, the heat supply of the buffer tanks and the heat rejection unit. It is based on the cold provided to the distribution system and thus includes possible cold losses. It should exclude the distribution system as this depends on the application and is not an inherent component of the cold production system. In the case of the installation at the winery it also comprises the electricity used for the direct evaporator of the wine bottle storage. Hence the electricity to provide the heat for the TDC is considered. So the solar collector system as well as the secondary side of the woodchip furnace boiler is represented in the $COP_{el,sys}$.

$$COP_{el,sys} = \frac{Q_{TdcCc}}{E_{Tdc} + E_{WP3} + E_{WP4} + E_{WP9} + EM405 + EM506 + (E_{WP80} + E_{WP1} + E_{WP2}) * fc} =$$

$$\frac{5019.7}{1370.5 + 368 * 0.24} = 3.44$$

E_{Tdc} = electricity used in the chiller = electricity used in the solution pump.

E_{WP3} = electricity used in driving circuit pump.

E_{WP4} = electricity used in the recooling circuit pump.

E_{WP9} = electricity used in the cold water pump.

EM405 = electricity used in the direct evaporator fan.

EM406 = electricity used in the cooling tower fan.

E_{WP80} = electricity used in the hot water pump on the secondary side of the wood chip boiler.

E_{WP1} = electricity used in the pump of the primary side of the solar collector system.

E_{WP2} = electricity used in the hot water pump on the secondary side of the solar collector system.

fc = factor cold describes the portion of heat that was used for cooling.

3.3. Solar contribution to driving heat of the TDC (thermally driven cooling system)

From May to November (cooling period) 100 % of the heat used in the TDC was provided by the solar collector system. In addition to that the solar system provided 44 % of the heat for the heating services of the winery. The remaining 56 % were provided by the wood chip fired boiler.

Table 1. Overview of the heat balance of the PolySMART system

	kWh
Heat provided by the wood chip boiler	31 823
Solar heat input	31 493
Heat for cooling	8 042
Other heating services	53 339
Losses of the buffer tanks	1 935

3.4. Stirling engine

The Stirling engine prototype was installed at the Trigeneration system of PolySMART in summer 2007 and first test runs were carried out in December 2007 and January 2008. The main goal was to develop and implement an automatic control system. This could be achieved.

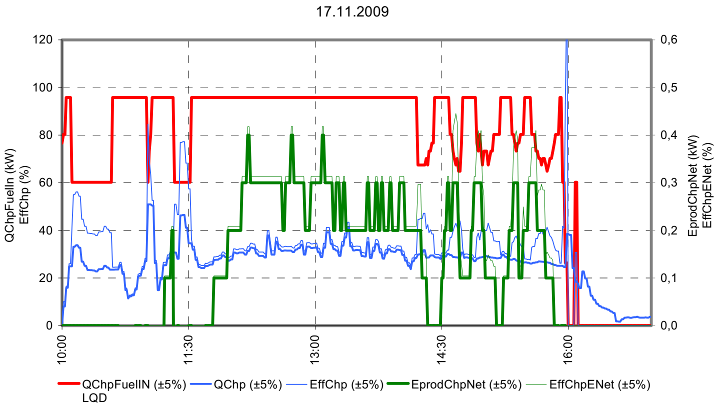

Fig. 4. Stirling energy balance and efficiency of a test run on the 17.11.2009

QChpFuelIn – energy content of the solid biomass fed into the furnace in kW.

QChp – heat fed into the buffer storage composed of the heat from the engine cooling cycles and exchanged heat from the flue gas water heat exchanger in kW.

EffChp – ratio of utilized heat plus electricity over QChpFuelIn.

EprodChpNet – net electricity produced by the generator in kW.

EffChpENet – EprodChpNet over QChpFuelIn.

Figure 4 illustrates the trigeneration run of the Stirling engine on the 17th of November 2009. It was one of several test runs where modifications and measurements within the engine were carried out. Here the automatic control system which was developed and implemented over the project duration was tested. The automatic control system started and stopped the engine automatically at set intervals. The Stirling engine did not operate automatically without supervision due to security issues which occurred (glowing steel pipes and flue gas flaps). The produced electricity therefore is very low. The reason is because the generator used is an asynchronous generator which operated outside its nominal conditions in terms of revolution speed. This leads to a low generator efficiency of 30 %. The mechanical output of the Stirling engine was as desired, between 1 and 2 $kW_{mechanical}$. It was measured with a load cell over the torque of the shaft. The relatively low overall efficiency of about 40 % is caused by:

- Poor generator efficiency of only 30 %.
- The flue gas heat exchanger is too small so the flue gas temperature was in the range between 200 °C and 270 °C.
- Very high waste heat radiation

4. Conclusions

4.1 Energy efficiency

The realized overall energy efficiency of about 40 % is relatively low. This is caused by:

- Poor electrical efficiency of the asynchronous generator.
- The flue gas / water heat exchanger is too small.

4.2 Operational behaviour, reliability of components and ease of installation and use

TDC: The system for the fully automatic operation of the solar driven TDC requires no further development. It worked without any disturbances throughout the monitoring period. The recommended inspection interval normally is not followed by maintenance works. The installation at the winery let to the development of the industrial product PinkChiller PC19, which can be purchased.

Stirling engine: From the operational behaviour of the Stirling engine at the present development stage, we suggest that it still requires further development efforts and cannot be considered market mature.

4.3 Maintenance

TDC: There is no maintenance required but a yearly inspection is recommended.

Heat rejection: A wet cooling tower designed like the one used in this project requires cleaning at least twice a year.

Stirling engine: There is no automatic operation possible at the present development stage

4.4 Achievements

A CHCP (combined heat, cold and power) technology in a commercial winery was successfully operated. A bio fuel powered Stirling engine for CHP-generation was successfully adapted:

It was shown that woodchip-fired Stirling based CHP is suitable for this application, even though a fully automatic Stirling engine operation was not possible for security issues occurring with the flue gas flaps. An existing control system was improved towards market maturity. A small ammonia/water absorption refrigeration machine was standardised and market maturity was proved.

4.5 Advice

Advice addressing wineries: The combined production of heat and cold from renewable resources like biomass and solar energy is a very good alternative to supply the specific energy demand of a modern winery. Especially the fact that solar energy is available simultaneously to the cooling demand of the wine storage makes the technology economically overly attractive. Most wineries also have access to free biomass. So, in general, it is advised that wineries introduce combined solar and biomass driven heat and cold production in order to reach more energy independence and cost effectiveness.

Advice for planners: The project has shown that the specific needs of a winery can be satisfied with the tested technology, especially in terms of solar and biomass driven heat and cold production. The system is operating very reliably and with very low maintenance effort.

Advice regarding biomass driven Stirling CHP: It was demonstrated throughout the project that, in general, the biomass driven Stirling technology works well, even though automatic operation still needs further improvements regarding efficiency, reliability and security.

References

[1] Podesser, E., Peitler J, Meißner E, Türschweller S. Enzinger P.: Einsatz von Sonnenenergie und Bioenergie zu Kühlung von vergärendem Weintraubensaft und zur Weinlagerraumkühlung, Bericht Nr.: IEF-B-09/03, JOANNEUM RESEARCH, Institut für Energieforschung, (2003)

[2] Podesser, E., Dermouz, H., Padinger, R., Wenzel, A., Entwicklung eines mit Holz betriebenen Stirling-Kleinkraftwerkes zur dezentralen Strom- und Wärmeerzeugung – Phase II, Bericht Nr.: IEF-B-12/95, JOANNEUM RESEARCH, Institut für Energieforschung, (1996).

[3] Weinbaukataster der Weinbau betreibenden Bundesländer, (1999).

[4] Podesser, E: Umweltverträgliche Kälteerzeugung, Bericht Nr.: IEF-B-6/94, JOANNEUM RESEARCH, Institut für Energieforschung, (1994).