The sun as a natural power plant

Powerful vacuum technology and reliable tightness control for improved efficiencies of solar receivers

When solar energy for electricity generation is discussed, photovoltaic systems most often come to mind. However, concentrated solar power systems are gaining popularity as an interesting alternative. In this type of power plants, collector systems concentrate sunlight and collect it on an absorber pipe. A heat transfer fluid in these absorbers or receivers transports the energy to a turbine which is connected to an electrical power generator.

This type of power plant is installed in regions that offer high levels of direct sunlight irradiation, for example, in Spain, the US (California and Arizona), and North Africa (Morocco). More recent installations are spreading all over the world including facilities in India, Israel, the Arabian Peninsula, South Africa, Australia and China.

The technology

Various concentrator technologies are using parabolic troughs, solar power towers, Fresnel reflectors, and hybrid systems using both solar power and synthesis gas as an energy source. The majority of installations is using parabolic troughs. In a solar thermal parabolic trough power plant, parabolic shaped mirrors concentrate solar radiation in an absorber pipe, the so-called receiver, positioned at the focal point of the reflectors. A heat transfer fluid such as thermal oil or molten salts pass through the receiver (see graphic 1). The receivers are connected in a series and lead the heat transfer fluid to the steam turbines in

the system's plant collector. Additional heat collectors in the plant can compensate for abrupt fluctuations in sun radiation and operation is also guaranteed during the night.

A solar thermal power plant with heat collectors can be planned as the energy production can be adapted to the consumption and/or the network load. The heat obtained in this way is pumped out and, by means of a heat exchanger, is used in a steam turbine for electricity generation. The parabolic trough technology has been proven and tested for many years and stands out due to a high degree of efficiency, high reliability and comparably low electricity generation costs.

Why vacuum?

Vacuum plays a decisive role for the power plant's efficiency: In order not to lose the obtained heat, the receiver (or collector) must be evacuated for vacuum insulation, the receiver comprises a hollow glass pipe and an internal steel tube. This design allows the different thermal expansion coefficients of glass and steel to be balanced out with flexible bellows in the event of temperature change. The heat-transfer steel pipe must be insulated without limiting the solar radiation. This type of vacuum insulation, similar to the thermo jug principle, and the use of special glass which permits a high transmission of sunlight, as well as special coatings on both tubes result in a significant reduction of radiation and convection loss.

Evacuation is performed at high temperature in a furnace where the receivers, structures with an individual length of typically 4 to 5 m, are connected to the pumping station. Adaptation to the pump is performed via a connecting nipple. From the vacuum technology point of view the diameter of the nipple needs to be as wide as possible for minimum conductance loss during the evacuation process.

However, the glass nipple still needs to be moltened off in order to hermetically seal the receiver tube. A compromise must be taken regarding the nipple dimensions which results in limited effective pumping speed at the nipple and comparatively long process times for thermal treatment. In this process step the surface of the receiver materials is degassed in order to minimize desorption gas load during long-term operation.

What pressure?

To effectively insulate the tubes, heat transported by convection must be prevented. If air is evacuated as the heat

Leak Detector ASI 35

transfer medium, heat is lost not as a result of convection but by radiation that transports considerably less heat than convection. Physically, a vacuum of below 10^{-3} mbar offers optimal heat insulation. As a result, the specified pressure must be maintained during the entire service life of the receiver. In addition, the gas supply caused by the permeation of sealing materials, desorption from the walls or leaks must be minimized.

To generate the required vacuum in the receiver, Pfeiffer Vacuum offers a wide range of vacuum solutions. Specially designed turbo pumping stations are used to evacuate receiver pipes that not only optimize vacuum technology but the shape is also adjusted to the production facilities.

An example of a customized pumping group is shown in Figure 1. In addition to vacuum technological parameters the components are selected for high resistance against glass particles after potential breakage of a receiver tube and the strong forces on the pumps going along with a sudden air inrush.

Leak tightness

The manufacturer of the receiver must guarantee the insulation for periods of at least 20 years so that efficiency is maintained in the power plant operation. Depending on the power plant's output, design, and the number of receivers connected together, every replacement of the receiver in the field entails an enormous expenditure of time and money.

100% tightness cannot be achieved technically. Therefore, it should be clarified as to how high the permeability may be and how far the pressure in the delivery status of the receiver must correspondingly lie under the guaranteed values in order to tolerate a pressure increase over a specified period.

The requirements for the maximum permitted leak rate Q_L result from the planned service life [s] of the receiver, the maximum permitted pressure increase [Pa] and the available volume [m³] in the hollow glass pipe:

$$\text{Leak rate} = \frac{\text{pressure rise x internal free volume}}{\text{service life period}} \text{ or } Q_L = \frac{\Delta p \times V}{\Delta t} \quad \frac{\text{Pa} \times \text{m}^3}{\text{s}}$$

As mentioned before, achieving a reasonable final pressure is limited by the geometry of the receiver and the flow resistance of the very narrow connection diameter of the pump port for evacuation from a technical vacuum perspective.

The molecular flow conditions in the high-vacuum prolong the pump-out times to lower pressures. The pressure reached in the receiver provides a practical compromise from the theoretically attained pressure and the permitted cycle times suitable for production.

Due to the limitations of leak rates and final pressure, the use of getter material may also be necessary, which further binds the emerging gas and keeps the pressure low. However, the challenge remains to ensure that, right from production, the insulation vacuum in the receiver is maintained throughout its service life. This tightness requirement is tested in a helium leak detector.

Why helium?

Helium is an inert gas, this means, it does not react with other substances. Other benefits include that helium is non-toxic and non-explosive, with clear costs. It does not harm the health of the operating personnel and, as a natural component of air, it does not harm the environment.

Several methods, according to internationally accepted regulations, can be used with the tracer gas and the detector technology based on mass spectrometry. This leads to unrivaled sensitivity and selectivity going along with easy calibration and high repeatability and reproducibility of the test.

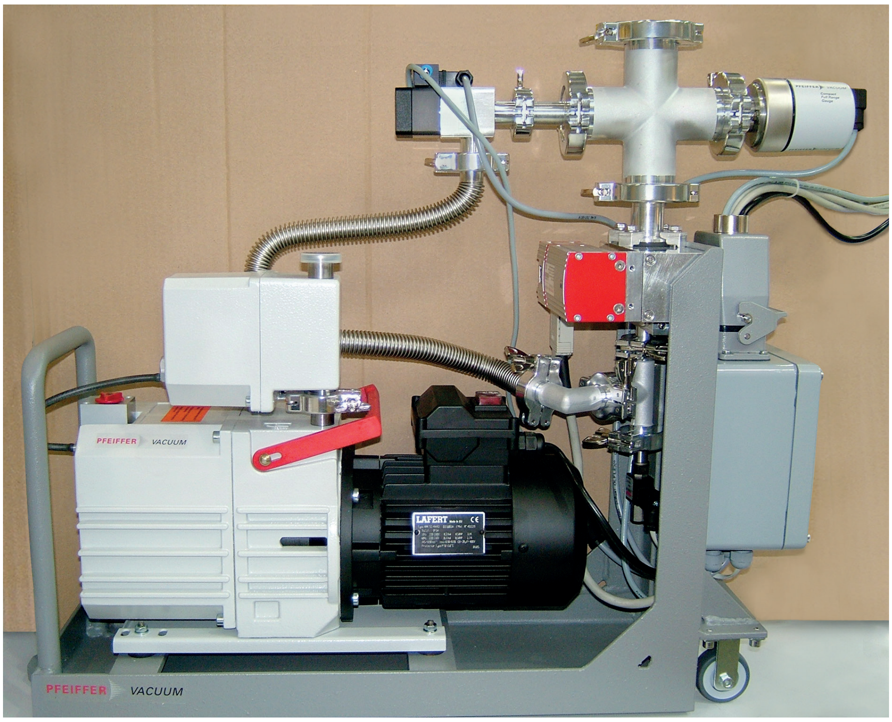


Fig. 1 Customized pumping cart for solar receiver degassing

The measuring method

Helium is a natural component of air with a natural concentration of 5 ppm. For highly accurate measurements, the residual helium portion of the air in the test chamber must be evacuated to generate an extremely low background signal. In order to be able to definitively detect the maximum permitted leak rate, the background signal must lie at least a half decade below the defined tightness requirement.

The helium atoms are detected with a sector field mass spectrometer, which is evacuated by a turbo molecular pump specially synchronized with the application. The test gas can thus be detected with the greatest possible accuracy and high selectivity already in a pressure range of lower than 1 mbar.

Integral/local leak detection

The tightness of the receiver must be integrally determined. Reliable evidence of the functioning of the tested receivers is vital in detecting all potential leakage points. A local leak detector can be used in localization of permeability spots for the purpose of reworking.

The testing direction should always correspond to the use in real-life. In the case of the receiver, this refers to the pressure difference between the atmospheric pressure and the evacuated room in the glass pipe. The weak points of the receiver pipes are the glass-metal junctions on both pipe ends. For integral leak detection, a filling chamber with a defined helium concentration is created, using an adaptation at the pipe ends.

Rotary vane pump DuoLine

This adaptation must be fully automatic for industrial use and is required for the defined application of the helium test gas. The leakage test must be conducted in compliance with ISO 20485 as both pressure and concentration are defined in the process.

The challenges posed by the technical implementation of a test system for receiver pipes lie in the adaptation to the cycle times of a production-based inspection as well as, from a vacuum perspective, in the difficult geometry of the test object and adaptations for pump system and test conditions.

In addition, the sensitivity of the leak detection effect of the receiver material and dead volumes, for example due to switching valves, must be taken into account.

Summary

Evacuation of solar receiver tubes is a compromise between the demands of vacuum requirements and glass processing technology. Dedicated pumping carts are used in order to provide for optimum vacuum performance going along with high ruggedness and a high level of protection in case of glass breakage.

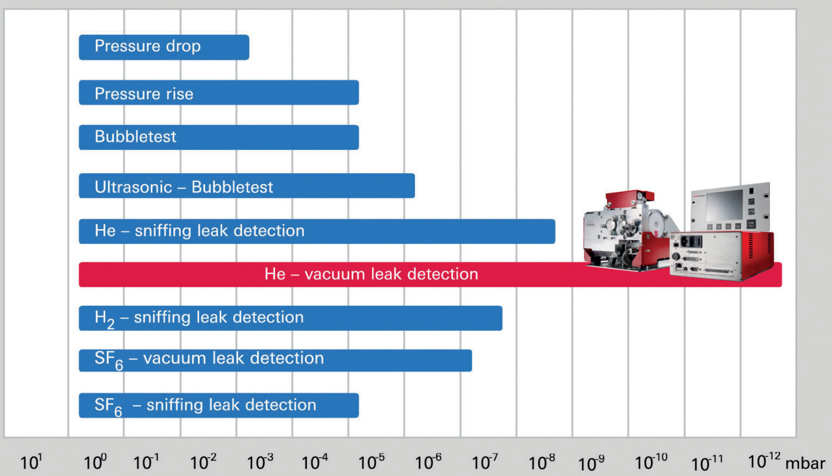
Inspection of the tightness of the receiver during production is a big challenge. In planning an industrial leak detection system for integration into modern production lines, process consistency and reliability can only be achieved with a fully automatic system. The complex physical parameters must be taken into consideration in order to fulfill the high-quality requirements and obtain reproducible results.

Pfeiffer Vacuum provides support with consultation and planning for the required systems and offers specially customized vacuum solutions for helium leak detection test and complete vacuum technology in the individual production steps.

www.pfeiffer-vacuum.com

Determination of the leak rate

According to today's quality standards, a 100% inspection of the leak rate is required in industrial production. In industrial practice, different methods for determining the leak rate have been established:



Leak rates in the range of below 10^{-6} mbar l/s can only be determined with certainty using the helium leak detector.