GENERAL DESCRIPTION

Mode of energy intake and output

Heat-to-heat

Heat transfer via radiation and convection between a gaseous or liquid transfer medium and an engulfed solid storage core.

Summary of the storage process

In solid-medium thermal storages, energy is stored by heating steel structures, natural rock fills, or artificial rocks, such as concrete or ceramic bricks. Suitable solids remain dimensionally and phase-stable, even at high temperatures. Their thermal capacity increases with temperature. State-of-the-art storages, depending on the material used, can reach any desired temperature, from about 250 to well over 1,000 °C.

There are several approaches to the charging and discharging process of solid-medium storages, depending mostly on the types of storage and heat transfer media used as well as the heat source and sink. Generally, a carrier medium (e.g. solar or electrically heated air, combustion gases, compressed air, or thermal oil) stands in direct contact with a solid bed or core, transporting heat to it or away from it directly or via a heat exchanger and secondary circuit with a different working medium.

The storage tank's geometry is essentially determined by its thermal storage capacity and the thermodynamically optimised arrangement of the storage medium. Special attention must be paid to ensuring uniform flow and minimal loss in the storage core while avoiding stress-related decomposition of the storage medium. Solid-medium storages can permanently and reliably power and decarbonise heat-controlled processes in industry and utility industry.

Focus on provision of power or energy

Energy

Suitable fields of application

The possible applications for solid storages are versatile and determined by the origin of the heat in the hot medium used for charging (e.g. waste heat, solar or electrically generated heat) and the utilisation of the discharge heat (e.g. for air preheating of a combustion process or for steam generation): Regenerator Storages are for example used for the intermediate storage of high-temperature heat and to increase energy efficiency in discontinuous processes, among others, in the glass industry, metallurgy, and cement production. In the blast furnace process, this type of storage is called *stoker-fired* or, after its inventor, *Cowper*, and 2 or 3 modules are linked together to provide hot blast (Fig. 1, left). Another application is the thermal-regenerative purification of exhaust air from hydrocarbons including an integrated heat storage with a charging/discharging capacity of 4 MW_{th} for exhaust air volumes of up to 200,000 Nm^3/h. Concepts for further applications are under investigation [9].

Figure 1: Cowper in a blast furnace process (left), thermal-oxidative exhaust air purification (right) (sources: [1], [2])

More recent applications and current R & D work aim to use regenerative storages in power plant applications: They can increase the operational flexibility of gas and steam turbine, coal-fired, as well as biomass or alternative fuel power plants. Goals are to improve load-switching capability, reduce the minimum load, and, in the case of cogeneration plants, to increase flexibility in the coupling of heat and power generation. One of the solutions investigated was the use of solid beds in the flue gas path of a gas turbine (Fig. 2, bottom. Similar investigations were carried out for biomass power plants (Fig. 3, bottom). In adiabatic compressed air energy storage plants, their use permits a considerable increase in electrical storage efficiency [1, 4]. Designs for storage capacities around 1 GWh_{th} were developed. In solar thermal power plants with air receivers, they allow for the temporal decoupling of solar irradiation and electricity generation. Pilot applications exist for this; the thermal heat storage in the Jülich solar tower plant can store 12 MWh_{th} at a discharge capacity of 5.7 MW_{th} (Fig. 4, bottom).

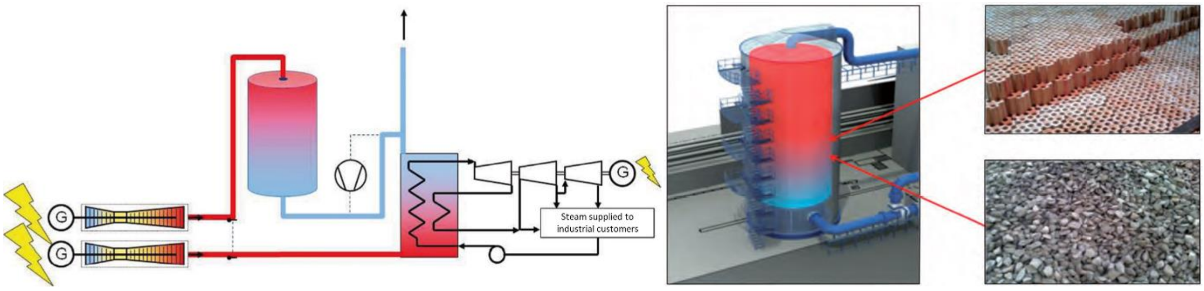

Figure 2: Integration of a solid bed storage in a 300 MW combined cycle gas turbine (© RWE/DLR) (sources: [5], [10])

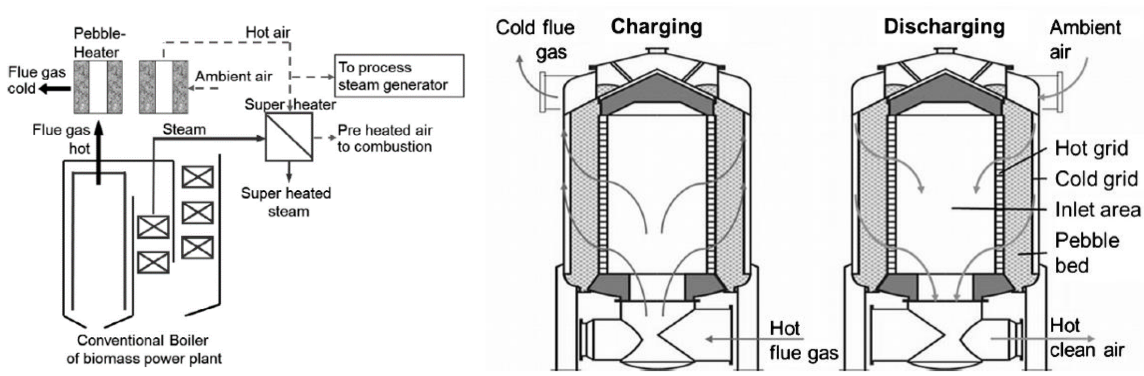

Figure 3: Solutions for the integration of a solid bed storage into a biomass power plant (© FhG Umsicht) (source: [8])

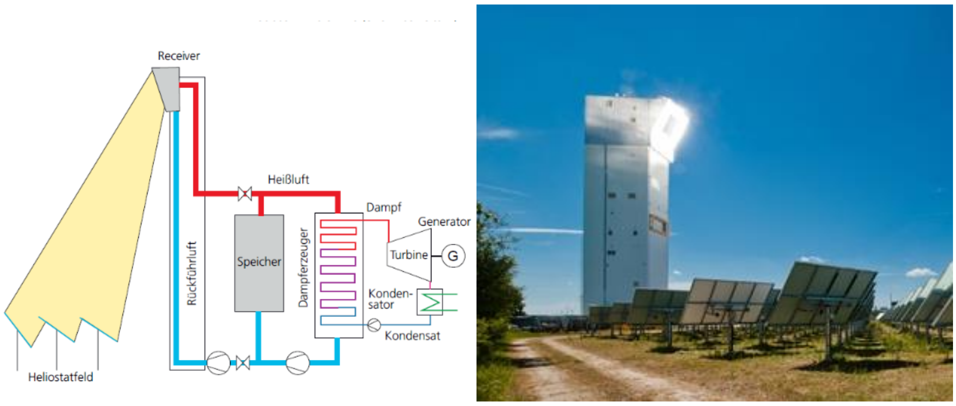

Figure 4: Integration of a brick storage into the Jülich solar power plant (source: [6])

Technology-Readiness-Level (TRL)

6-7

State of development/commercial availability

Regenerative storages are commercially available for use in the steel and glass industry as well as for exhaust air purification. Their use in power plant technology is application-oriented, but still pre-commercial. The technology has been implemented on a pilot scale in the Jülich solar tower power plant.

TECHNICAL SPECIFICATIONS

Specific energy storage density	kWh/m^3 70-150	kWh/t 50-100
Specific power density	kW/m^3 20-40	kW/t 15-25
Typical/feasible storage size	$MWh_{th\ out}$ 1-1,000	$MW_{th\ out}$ n.a.
Storage efficiency	98 %	
Storage duration	Hours-days	
Response time	Minutes	
Service life (maximum)	Cycles > 10,000	Years > 20
Loss per time in %	2-4 % of nominal capacity per 24 h	

ECONOMIC SPECIFICATIONS

Investment cost per kW

100-150 € per 6 h of storage

Investment cost per kWh

15-40 €

Operating and maintenance cost (based on investment/kWh_{th})

1 % of overall investment per year

Notes on these specifications

The given specific costs refer to the factory price of a heat storage. The cost of transport, installation, and commissioning is country-specific.

Cost of provided energy in concrete application

Melting furnace waste heat utilisation: 1 MWh_{th} per batch, 12 batches per day = 12 heat storage cycles per day
Storage size: 1.3 MWh_{th}
Waste heat is used for preheating the melting materials and combustion air of the heating equipment of the melting furnace. Added electrical power requirement for fans: 3 kW
Natural gas savings: 45 m^3/h, (about 75,000 €/year)
Total system investment: about 300,000 €

For further information, see

[1] Laing, Doerte and Zunft, Stefan (2014) *Using concrete and other solid storage media in thermal energy storage (TES) systems.* In: Advances in Thermal Energy Storage Systems. Methods and Applications. Woodhead Publishing Series in Energy. Woodhead. Pp. 65-86. ISBN 9781782420880.

[2] Krüger, Michael and Dreißigacker, Volker and Zunft, Stefan and Meier, Hans-Joachim (2015) *Flexibilisierung von Kohlekraftwerken durch Integration von Wärmespeichern: Ergebnisse des Verbundvorhabens Partner-Dampfkraftwerk.* In: Kraftwerkstechnik 2015: Strategien, Anlagentechnik und Betrieb. SAXONIA. Kraftwerkstechnisches Kolloquium, Dresden. ISBN 3934409709.

[3] Zunft, Stefan and Hänel, Matthias and Krüger, Michael and Dreißigacker, Volker (2013) *A design study for regenerator-type heat storage in solar tower plants – Results and conclusions of the HOTSPOT project.* Energy Procedia 49 (2014) 1088-1096, doi: 10.1016/j.egypro.2014.03.118.

[4] Zunft, S., Krüger, M., Dreißigacker, V., Mayer, P.-M., Niklasch, C. and Bertsch, C., 2012. *Adiabate Druckluftspeicher für die Elektrizitätsversorgung – der ADELE-Wärmespeicher.* In Kraftwerkstechnik, vol. 4. Dresden: TK Verlag, pp. 749-757.

[5] Zunft, Stefan and Dreißigacker, Volker and Krüger, Michael (2014) *Einsatz von Hochtemperaturspeichern in der Kraftwerkstechnik und ihre Entwurfsaspekte.* In: Kraftwerkstechnik 2014 - Strategien, Anlagentechnik und Betrieb, Seiten 637-646. Saxonia. 46. Kraftwerkstechnisches Kolloquium, 14.-15. Oktober 2014, Dresden. ISBN 978-3-934409-62-0.

[6] Zunft, Stefan and Hänel, Matthias and Krüger, Michael and Dreißigacker, Volker and Göhring, Felix and Wahl, Eberhard (2011) *Jülich Solar Power Tower – Experimental Evaluation of the Storage Subsystem and Performance Calculation.* Journal of Solar Energy Engineering, Volume 133 (Issue 3), pp. 1019-1023. American Society of Mechanical Engineers International. doi: 10.1115/1.4004358. ISSN 0199-6231.

[7] KBA-Metalprint, http://www.kba-metalprint.com/kba-cleanair/produkte/product/tra-thermisch-regenerative-abluftreingung.

[8] Daschner, R., Binder, S., Hornung, A.: *Pebble bed regenerator and storage system for high temperature usw.* Applied Energy 109 (2013), 394-401.

[9] Konzept zur Abwärmenutzung bei Schmelzanlagen, Fa. KBA-Metalprint, http://www.kba-metalprint.com/kba-cleanair/produkte/product/thermischer-energiespeicher-tes/detail/

[10] Stahl, K. and Zunft, S. (2012) *Entwicklung eines Hochtemperatur-Wärmespeichers zur Flexibilisierung von GuD-Kraftwerken.* In: Kraftwerkstechnik, vol. 4, pp. 777-784. TK Verlag. 44. Kraftwerkstechnisches Kolloquium, Oktober 2012, Dresden. ISBN 978 3 935317 87 0.