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EVALUATION OF THE GASOMETRIC COVERAGE SYSTEM **"CUPOLA M3 HEAT SHIELD®"** IN REDUCING HEAT LOSSES FROM THE ANAEROBIC DIGESTERS

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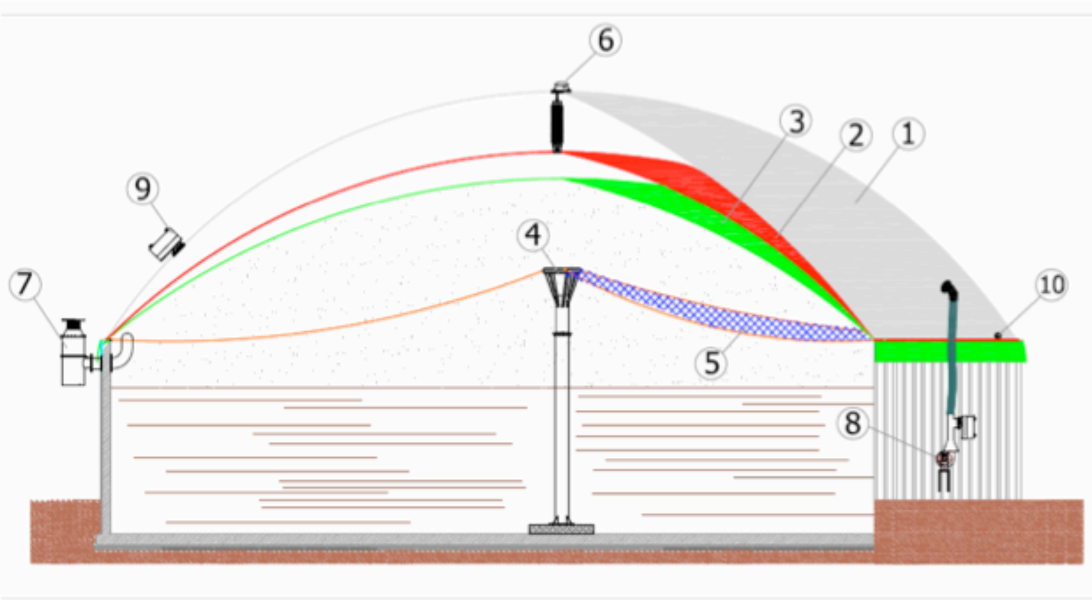
This report presents the results of a comparative study carried out with the objective to assess the effectiveness of the gasometric coverage system "CUPOLA M3 HEAT SHIELD® (HSs)" (Figure 1) in reducing heat losses from the digesters.



1	EXTERNAL DOUBLE-SIDED PVC COATED POLYESTER FIBRE FABRIC MEMBRANE
2	SPECIAL INSULATED INTERMEDIATE MEMBRANE
3	INTERNAL DOUBLE-SIDED PVC COATED POLYESTER FIBRE FABRIC MEMBRANE
4	CENTRAL COLUMN
5	NET AND BANDS SUPPORT SYSTEM
6	LEVEL MEASURER
7	SAFETY VALVE
8	AIR FAN WITH OVERPRESSURE VALVE
9	SAFETY OVERPRESSURE VALVE
10	ONE-WAY VALVE

Fig. 1 The main components of the gasometric coverage system "CUPOLA M3 HEAT SHIELD®

The study has been carried out at the anaerobic digestion plant (ADP) of the Cooperativa Speranza located in Candiolo, Turin (northwest Italy). The ADP is a completely stirred tank reactor operating in mesophilic conditions (41°C), with an installed electrical power of 998 kWel and a nominal thermal power of 994 kWth. It consists of two identical 7600 m^3 cylinder-shaped anaerobic digesters, named D1 and D2, each formed by two chambers concentrically arranged and connected to the bottom (Figure 1).

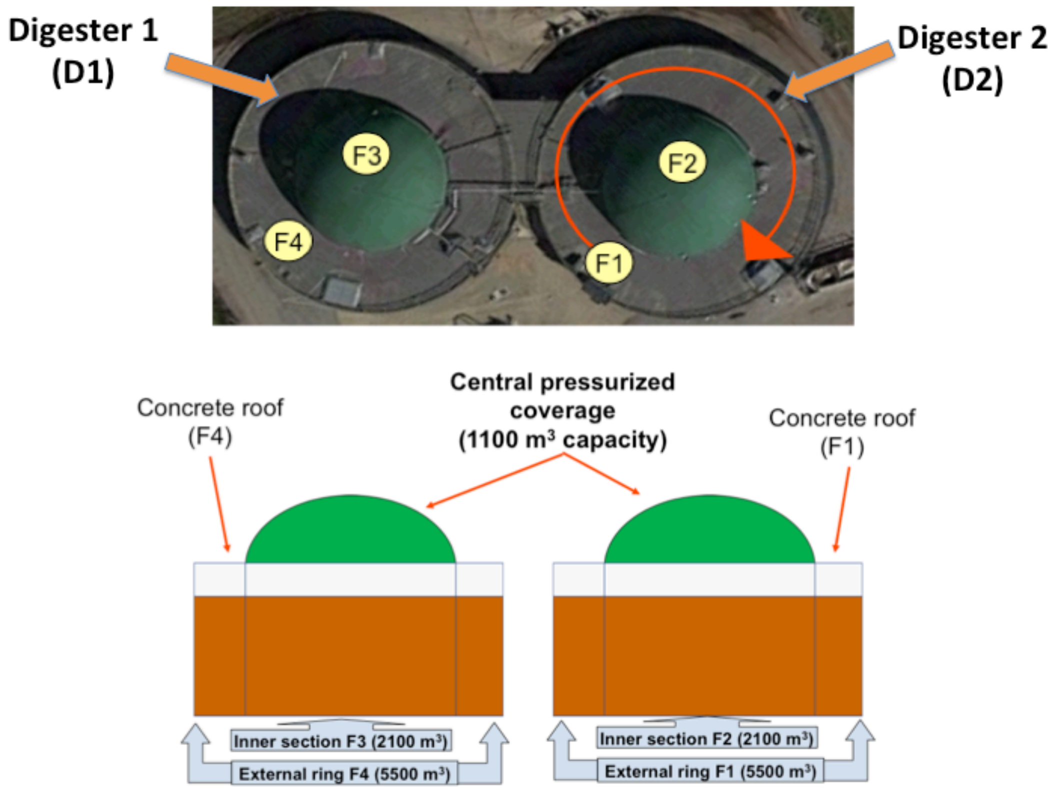


Fig. 1 The biogas plant at the Cooperativa Speranza (Candiolo, TO)

The external chambers (F1, F4) of each digester are covered with insulated concrete, whereas the internal chambers (F2, F3) are set up with a traditional double pressurized membrane (PVC-coated on both sides) coverage system for biogas storage (1100 m^3 total capacity). The pressurised outer membrane-layer of each coverage system has a total surface area of 1520 m^2.

The heating system consists of stainless-steel heating pipes positioned on the chambers inner walls. Chambers F1 and F4 are equipped with a 1 long axis and 2 paddles (1 vertical, 1 horizontal) agitator units, whereas the internal chambers are fitted with 3 propeller mixers.

Material and Methods

For the purpose of the study, F3 was covered by a HSs identical to the existing traditional gasholder system of digester D2 (Reference) in terms of shape, gas holder volume, type of material (double-sided PVC coated polyester fiber) and color shade of the external layer (Figure 2).

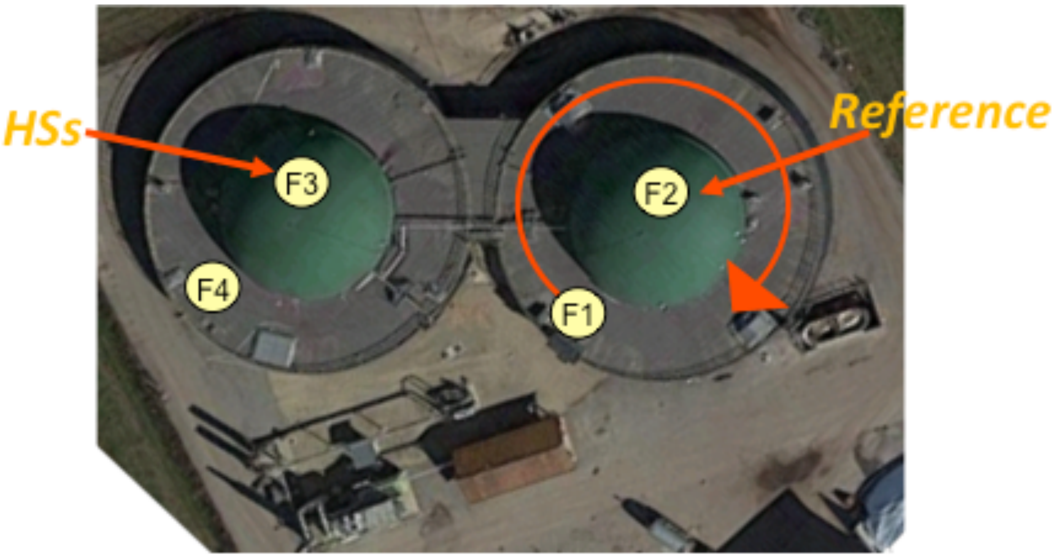


Fig. 2 The two investigated gasometric coverage systems at the biogas plant of the Cooperativa Speranza (Candiolo, TO)

Heat losses from HSs were measured and compared to those from the traditional gasholder system (digester D2, Reference) during one measuring campaign in late summer (Exp. 1), and two measuring campaigns in winter (Exp. 2 and Exp. 3) conditions (Table 1).

Table 1 Experimental layout and main operating parameters of the selected anaerobic digestion plant

Exp. (n)	Environ. conditions	Main operating conditions of the selected ADP			
		Feedstock composition	HRT (days)	Temp. (°C)	Biogas volume within the gasometer (% on total capacity)
1	Late summer	Animal manures (66%) Energy crops (29%) Agricultural by-products (5%)	~ 130	~ 41	90
2	Winter				70
3	Winter				70

During each experiment both digesters were operated identically, particularly as regards the following parameters:

- feedstock (a mixture of animal manures, energy crops, agricultural by-products);
- process temperature (approx. 41 °C);
- organic loading rate (1.55 kg volatile solids * m^{-3} fermenter day^{-1});
- hydraulic retention time (approx. 130 days);
- level of fermenting substrate inside the digester;
- mixing frequency and duration;
- biogas volume within the gasometer;
- the air flux and the working pressure of the gasholder dome.

Heat losses through the investigated gasometric coverage systems were estimated according to ISO 9869, by using a thermal imaging camera (AVIO mod. TVS-500) and a wireless heat flux meters (ThermoZig) (Figure 3).

 (AVIO mod. TVS-500)	 (ThermoZig)
a	b

Fig. 3 The thermal imaging camera (a) and the wireless heat flux meter (b) used for the determination of heat fluxes from the investigated gasometric coverage systems.

Thermal inspection by the infrared camera allowed to verify the absence of thermal anomalies (e.g., thermal bridges), and the subsequent selection of representative surface areas for accurate measurement of the heat flow rate through the digester covers. The acquisition of thermal images was conducted at a constant distance from the covers. The average surface temperature of the investigated covers was calculated using Goratec Thermography Studio Professional software in which each pixel of the picture was allocated to one temperature value. An arithmetic mean was subsequently created on the basis of all values.

The heat flux meters used in this study (Figure 3b) consist of a circular plate (80Ø x 5.5 mm) equipped with sensors for measuring the temperature of the side in contact with the emitting surface, a heat flux sensor, and a data logger. After thermal inspection, the heat flux meters were placed on the selected surface areas (Figure 4) and the heat flow rates through the investigated gasometric coverage systems measured simultaneously.

Fig. 4 The device used for the determination of heat fluxes placed on the surface of the HSs gasometric coverage system.

According to ISO 9869 each experiment lasted for at least 72 hours. However, solar-radiation may induce errors in the heat flux readings. Furthermore, according to the recommendations of the instrument manufacturer, for accurate and reliable heat fluxes estimation, heat flux measurement devices shall be operated when the temperature difference across the internal and external surface of the system under investigation is higher than 10°C.

Based on the above-mentioned consideration and operational aspects (i.e., the need for achieving homogeneous conditions within the gasometric coverage systems), only data recorded during the evening or night-time hours were considered valid for the purpose of this study. In particular, heat fluxes in late summer conditions (Exp. 1) were calculated based on data recorded from 2:00 am to 6:00 am. With regard to winter trials, heat fluxes estimation considered data collected from 7:00 pm to 12:00 (midnight) for Exp. 2, and from 1:00 am to 5:00 am for Exp. 3. A wireless weather station (Davis Vantage Pro2^{TM}) was placed equidistant from the two digesters and fixed at 6.5 m above the ground (i.e., approx. 1 m above the base of the gasometric coverage systems), for continuous measurement of ambient temperature, air relative humidity and wind speed.

Results

Table 2 reports the environmental parameters and heat losses measured during the experimental trials.

Table 2 Environmental conditions and heat losses measured during the experiments

	Experiment (n) 1	2	3
Aver. air relative humidity (%)	89.0	90.9 (86.0 / 94.0)	94.0 (93.0 / 94.0)
Aver. wind speed (m s^{-1})	0.1	0.2 (0.0 / 1.3)	0.2 (0.0 / 0.9)
Aver. air Temperature (°C)	14.0	-0.4 (-1.2 / 0.9)	-2.1 (-1.6 / -2.6)
Aver. Temperature of the external covers surface (°C):			
- Reference	12.4 (8.5 / 14.4)	0.6 (-3.6 / 3.2)	2.4 (1.2 / 3.4)
- HSs	10.5 (5.9 / 12.6)	-1.7 (-5.7 / 0.3)	0.7 (-0.4 / 1.7)
Aver. Heat losses (W m^{-2}):			
- Reference	**38.7 (44.4 / 35.3)**	**64.9 (61.2 / 68.3)**	**66.5 (64.5 / 68.2)**
- HSs	**20.1 (29.5 / 15.2)**	**32.6 (29.8 / 34.5)**	**34.5 (32.3 / 36.5)**

As expected, the measured heat losses from the gasometric coverage systems were positively correlated ($p<0.05$) with environmental and external covers surface temperature, with average emission fluxes approximately 40% higher in winter than in late summer conditions.

Thermal imaging measurements (Figures 5, 6 and 7) showed that, irrespective of environmental condition, the distribution of the temperature on the covers surface varied vertically, with values decreasing from the base to the apex of the domes.

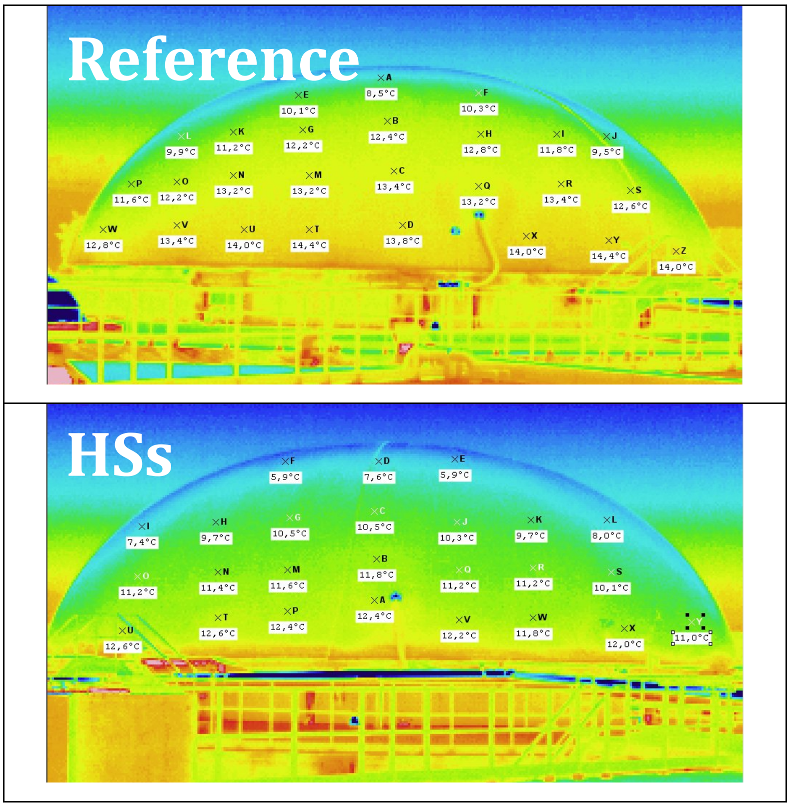


Fig. 5 Thermal image of the tested gasometric coverage systems during Experiment 1 (summer conditions).

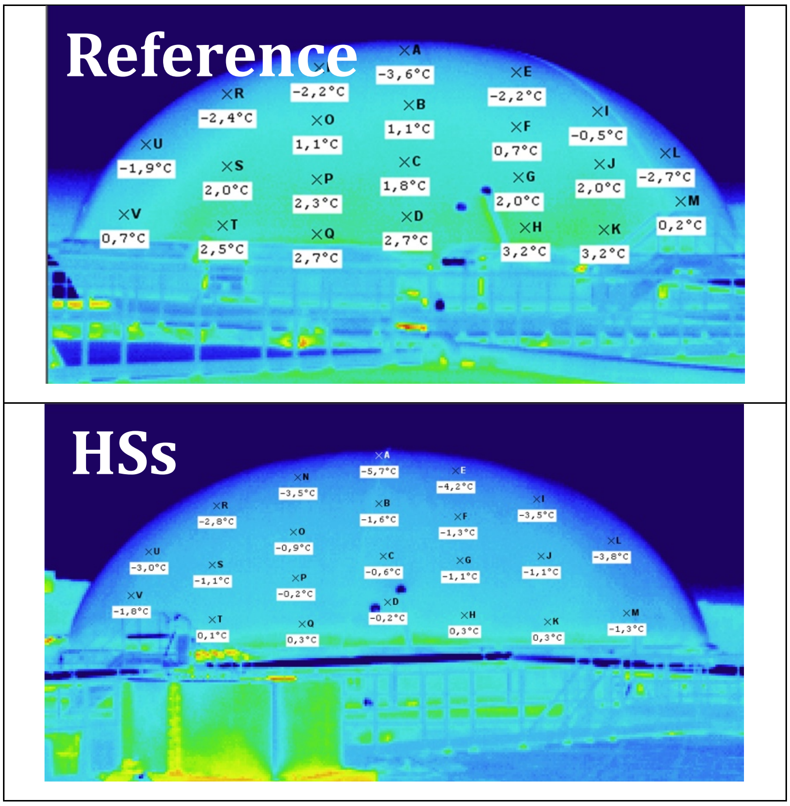


Fig. 6 Thermal image of the tested gasometric coverage systems during Experiment 2 (winter conditions).

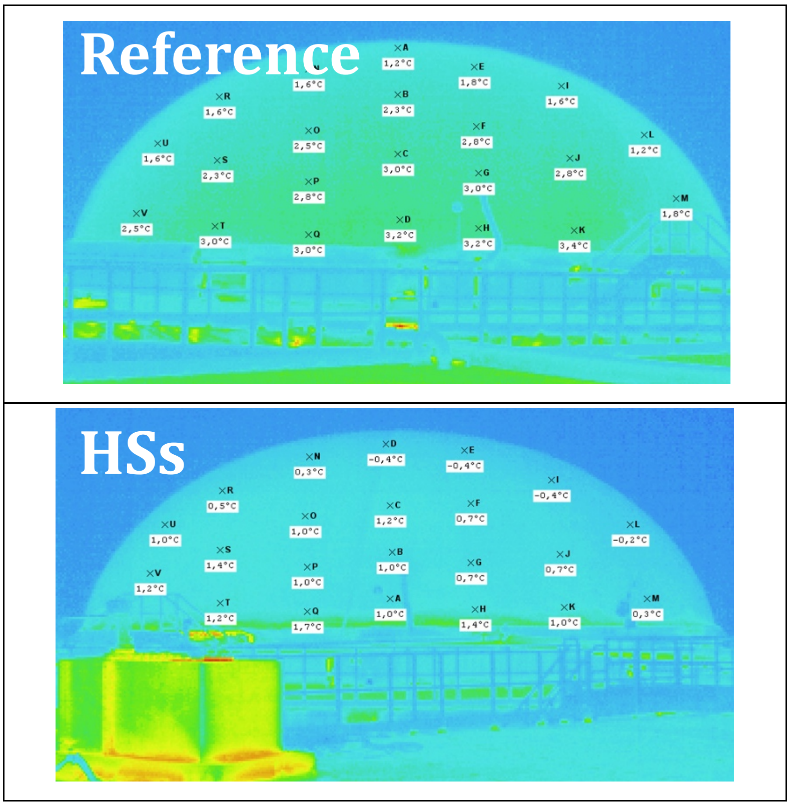


Fig. 7 Thermal image of the tested gasometric coverage systems during Experiment 3 (winter conditions).

It should be noted that in winter conditions the minimum temperatures measured on specific areas of the external covers surface were sometimes lower than the air temperature (Table 2), due to the fact that the weather station was placed at a different height above the ground level.

Heat losses from the Reference averaged 38.7 W m^{-2} in late summer and 65.7 W m^{-2} in winter (Table 2), corresponding, respectively, to 29.4 kW and 49.9 kW if referred to the total surface area (1520 m^2) of the coverage system.

Under all experimental conditions, heat losses measured from the Reference were significantly ($p<0.05$) higher than those recorded from the HSs. The environmental conditions did not affect the emission reduction performance of the HSs system. Specifically, HSs showed reduced emission fluxes on average by 48.1%, 49.8% and 48.1% in Exp. 1 (late summer conditions), Exp. 2 and Exp. 3 (winter conditions), respectively.

Conclusions

The experimental results showed that HSs is an effective system for reducing heat losses from the digesters. Under the specific conditions of this study HSs abated approximately 50% heat losses as compared to the traditional double membrane pressurized gasholder system.

Grugliasco, 18/12/18