Data in Brief 32 (2020) 106323

Contents lists available at ScienceDirect

Data in Brief

journal homepage: www.elsevier.com/locate/dib

Data Article

Measured and derived data at the exhaust of a batch industrial dryer

Gianluca Valenti[a,*], Camilla Nicol Bonacina[a], Abdullah Bamoshmoosh[a]

[a] *Politecnico di Milano, Dipartimento di Energia, Via Lambruschini 4A, 20156 Milano, Italy*

ARTICLE INFO

Article history:
Received 6 August 2020
Revised 7 September 2020
Accepted 16 September 2020
Available online 20 September 2020

Keywords:
Natural gas-fired dryer
Dryer conditions
Cotton fabric dryer
Exhaust air temperature
Exhaust air velocity
Anemometer measurements

ABSTRACT

This work reports the measured and derived quantities of an experimental campaign conducted in an existing laundry to record the conditions of the exhaust air of a batch industrial natural gas-fired dryer for cotton flat fabrics, like bed linens or tablecloths. The load of fabrics is 85 kg, referred to the dry fabric. The measured quantities are temperature and velocity in the center of a squared exhaust duct, which are reported along with their measurement uncertainty. The derived quantity is the exhaust air mass flow rate along with its combined uncertainty. In particular, these data can be used to study the feasibility of waste heat recovery strategies, such as that studied in the related research article "Optimal cascade phase change regenerator for waste heat recovery in a batch industrial dryer" [1].

DOI of original article: 10.1016/j.csite.2020.100734

* Corresponding author(s).
E-mail address: gianluca.valenti@polimi.it (G. Valenti).

https://doi.org/10.1016/j.dib.2020.106323

Specifications Table

Subject	Energy (General)
Specific subject area	Temperature, velocity and mass flow rate of the exhaust air from a batch industrial natural gas-fired dryer for cotton flat fabrics
Type of data	Table
How data were acquired	A mobile hot wire anemometer, namely Testovent 4000, is used to measure the temperature and the velocity of the dryer exhaust air in the middle of a squared duct. The industrial dryer is loaded with wet cotton flat fabrics; the weight of the fabric is 85 kg referred to the dry conditions. Then, the mass flow rate of the exhaust air is derived from the measured temperature and velocity. Moreover, the combined uncertainty of the mass flow rate is computed from the relative measurement uncertainties of temperature and velocity. Ultimately, humidity is estimated approximately assuming an initial quantity of water in the wet fabric being released constantly during the drying process.
Data format	Raw Derived
Parameters for data collection	Temperature and velocity are recorded every 30 s during a drying cycle of 17 min. This is repeated over 3 cycles for comparison, but the last one is taken as reference. Mass flow rate is derived assuming ideal gas behavior, ambient pressure, dry air molar mass and fully developed flow. Its combined uncertainty is calculated considering temperature and velocity as sources of uncertainty.
Description of data collection	Temperature and velocity are measured at the center of a 500 mm squared exhaust duct with the probe of the instrument directed parallel to the flow. Quantities are recorded manually. After the test, mean velocity at each recorded instant is derived from center velocity by a correction factor, density from temperature as well as assumed thermodynamic behavior, and mass flow rate from mean velocity and density. Combined relative uncertainty of mass flow rate is calculated from temperature and velocity uncertainties, whose values are provided in the instrument manual.
Data source location	City/Town/Region: Segrate (Milano) Country: Italy Latitude and longitude: 45.4898143, 9.2684387
Data accessibility	With the article
Related research article	Gianluca Valenti, Camilla Nicol Bonacina, Adbullah Bamoshmoosh, Optimal cascade phase change regenerator for waste heat recovery in a batch industrial dryer, Case Studies in Thermal Engineering, 22 (2020) doi:10.1016/j.csite.2020.100734

Value of the Data

- This dataset is useful to describe quantitatively the exhaust conditions of industrial natural gas-fired batch dryers for cotton flat fabrics. It can be used to study the feasibility of waste heat recovery strategies applied to dryers that are technologically and operatively comparable to that studied in the present work. In particular, the dataset is useful to assess the technologies that recover the energy from the exhaust gases to preheat the ambient air entering the dryer burner, as in the related research article, as well as to produce hot water for industrial use and also for space heating.
- The data can be useful for manufacturers as well as researchers that need an indication of the operative conditions of the exhausts of industrial batch dryers. Generally, the instrumentation to provide these data is not included in the dryer control system and, thus, lack of this information can be an issue for personnel working in this field.

- These data can be further used to study the feasibility of different waste heat recovery systems to decrease the natural gas consumptions of the dryer itself. Indeed, many studies for heat recovery from industrial dryers are available in literature, but they focus mainly on continuous applications rather than batch applications as that studied in this work.

1. Data Description

This work reports the measured and derived quantities of an experimental campaign conducted in an existing laundry to record the conditions of the exhaust air of a batch industrial natural gas-fired dryer for cotton flat fabrics, like bed linens or tablecloths. The load of fabrics is 85 kg, referred to the dry fabric. The overall cycle lasts 20–22 min, comprised of loading, pre-heating, drying, post-cooling, unloading of the fabrics, and cleaning of the dryer itself. For the scope of this work, the sole heating, drying and cooling phase of 17 min is considered. Fig. 1 pictures the industrial dryer.

The probe of the hot wire anemometer Testovent 4000 is inserted up to the center of the squared exhaust duct to measure the dryer exhaust temperature T (°C) and velocity v_c (m/s) every 30 s over the reference drying cycle, resulting in 35 samplings for the cycle. The temperature and velocity uncertainties, as stated in the anemometer manual, are 0.5°C + 0.3% of the measured temperature and 0.2 m/s + 1.5% of the measured velocity, respectively. These values coupled with the direct measurements of temperature and velocity, respectively, allow to compute for each instant the relative uncertainties of both temperature and velocity, u_T (-) and u_v (-). Fig. 2 pictures the probe in the exhaust duct, while Fig. 3 schematizes the industrial dryer and the duct with the probe. Furthermore, Table 1 reports the raw quantities and the relative uncertainties of these samplings.

From the measurements and relative uncertainties of the temperature and velocity, it is possible to compute the exhaust mass flow rates $\dot{m}$ (kg/s) and their relative uncertainties u_m (-) for each sampling over the drying cycle, as explicated in the next paragraph. Table 2 shows the

Fig. 1. The batch industrial natural gas fired dryer for cotton flat fabrics considered in this work (the exhaust duct is in the upper right part).

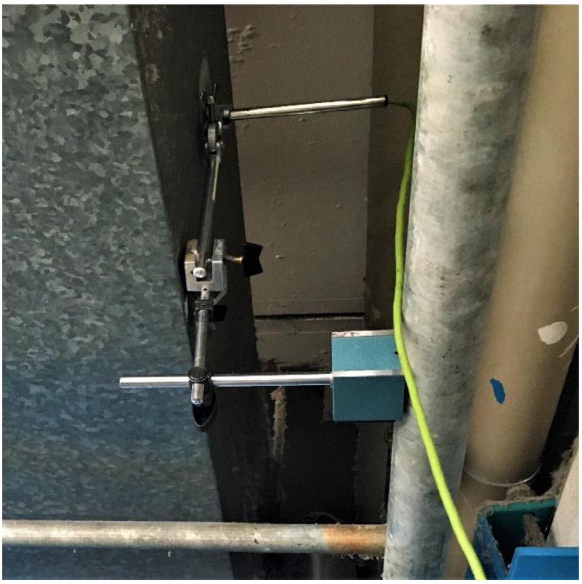

Fig. 2. The probe of the hot wire anemometer Testovent 4000 inserted in the squared 500 mm exhaust duct.

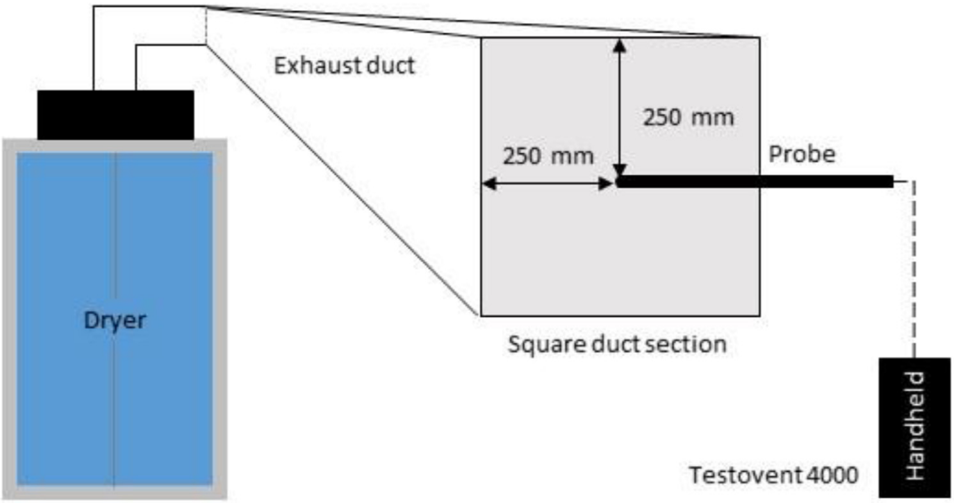

Fig. 3. The probe of the hot wire anemometer Testovent 4000 inserted in the squared 500 mm exhaust duct.

calculated mass flow rates and the corresponding relative uncertainties (always as percentage value) of the samplings.

Moreover, the absolute humidity of the exhaust air is estimated to be 0.04 $kg_{water}/kg_{dry,air}$, assuming a constant release of evaporated water over the drying cycle, as explained in the next section.

Table 1
Raw quantities and relative uncertainties of the measured temperature and velocity in the center of the exhaust duct over the reference drying cycle.

Instant (min)	T (°C)	u_T (%)	v_c (m/s)	u_v (%)
0.0	48.8	1.3	4.8	5.7
0.5	57.4	1.2	4.6	5.7
1.0	68.5	1.0	4.8	5.6
1.5	76.4	1.0	4.8	5.6
2.0	83.7	0.9	4.7	5.6
2.5	84.7	0.9	4.5	5.8
3.0	95.7	0.8	4.5	5.8
3.5	97.5	0.8	4.4	5.9
4.0	102.0	0.8	4.1	6.3
4.5	103.3	0.8	4.4	5.9
5.0	106.0	0.8	4.3	6.0
5.5	109.5	0.8	4.3	6.0
6.0	110.8	0.8	4.3	6.0
6.5	110.0	0.8	4.0	6.4
7.0	109.7	0.8	4.1	6.3
7.5	108.3	0.8	4.2	6.2
8.0	109.2	0.8	4.0	6.4
8.5	108.8	0.8	4.0	6.4
9.0	109.3	0.8	4.0	6.4
9.5	110.4	0.8	4.0	6.4
10.0	109.8	0.8	3.9	6.5
10.5	112.4	0.7	3.8	6.7
11.0	112.4	0.7	3.9	6.5
11.5	113.6	0.7	3.8	6.7
12.0	115.0	0.7	3.9	6.5
12.5	110.9	0.8	3.8	6.7
13.0	109.2	0.8	3.7	6.8
13.5	107.1	0.8	3.5	7.1
14.0	104.1	0.8	3.6	6.9
14.5	104.1	0.8	3.5	7.1
15.0	101.4	0.8	3.4	7.3
15.5	98.0	0.8	2.6	9.1
16.0	95.7	0.8	2.5	9.4
16.5	93.6	0.8	2.6	9.1
17.0	92.1	0.8	2.5	9.4

2. Experimental Design, Materials and Methods

2.1. Measured quantities

The instrument used to perform the measurements of temperature and velocity is the mobile hot wire anemometer Testovent 4000, as anticipated. The probe comprises a NiCr-Ni thermocouple to measure the temperature as well as an impeller to measure the velocity. The systematic error due to the frictional effects is corrected automatically. In terms of operating mode, the measures are performed each 30 s in the center of the 500 mm squared exhaust duct, as far as possible from the dryer exit section to consider fully developed conditions of the flow. A hole is made in the duct, and the instrument is held by an arm and fixed by a magnetic base. Indeed, movements of the probe must be avoided for the flow to bbe parallel to the impeller axis. Great care is paid to insert the probe with the impeller and the thermocouple parallel to the flow direction. Moreover, the process conditions may change cycle by cycle depending on the type of fabrics and variability of the process. Thus, the measurements are repeated for three consecutive cycles to perform a qualitative comparison; however, only the last cycle is taken as reference for the quantitative analysis described in the previous paragraph.

Table 2
Derived quantities and relative uncertainties of the mass flow rate calculated over the reference drying cycle.

Instant (min)	$\dot{m}$ (kg/s)	u_m (%)
0.0	1.22	6.1
0.5	1.14	6.3
1.0	1.15	6.1
1.5	1.13	6.1
2.0	1.08	6.1
2.5	1.03	6.4
3.0	1.00	6.3
3.5	0.97	6.4
4.0	0.90	6.8
4.5	0.96	6.4
5.0	0.93	6.6
5.5	0.92	6.6
6.0	0.92	6.6
6.5	0.86	6.9
7.0	0.88	6.8
7.5	0.90	6.7
8.0	0.86	6.9
8.5	0.86	6.9
9.0	0.86	6.9
9.5	0.86	6.9
10.0	0.84	7.1
10.5	0.81	7.2
11.0	0.83	7.1
11.5	0.81	7.2
12.0	0.82	7.1
12.5	0.81	7.2
13.0	0.79	7.4
13.5	0.75	7.7
14.0	0.78	7.5
14.5	0.76	7.7
15.0	0.74	7.9
15.5	0.57	9.8
16.0	0.56	10.2
16.5	0.58	9.8
17.0	0.56	10.2

2.2. Derived quantities

The mass flow rate of the exhausts $\dot{m}$ (kg/s) is calculated from the direct measurements of temperature and velocity as follows [2]

$$\dot{m} = \rho v_m A = \frac{M\,P}{\mathcal{R}(T + 273.15)} v_m L^2 \tag{1}$$

where ρ (kg/m^3) is the density calculated assuming ideal gas conditions, v_m (m/s) the mean velocity of the exhaust air, and A (m^2) the cross section of the squared duct. The molar mass of dry air M, the pressure P and the universal gas constant $\mathcal{R}$ are assumed to be equal to 28.9 kg/kmol, 100 kPa and 8314 J/(kmol K), respectively. In its turn, the squared duct side L is 0.5 m. The ideal gas assumption is validated by the estimation of the air absolute humidity reported in the previous section and performed as explained in the next paragraph. Indeed, considering the absolute humidity for the calculation of the mass flow rate would lead to a variation of the results well below the uncertainty of the mass flow rate itself. Incompressible flow and constant cross section of the duct are assumed to compute the exhaust mean velocity v_m. In this way, the velocity is independent on the position along the axial direction of the duct, and the only variation of the velocity along the radius must be determined. Moreover, the assumption of fully developed condition ensures the radial component of the velocity and the gradient of the axial velocity component to be null everywhere in the cross section.

The mean velocity in the squared section of the duct is calculated via correlations for circular ducts adopting the hydraulic diameter $D_h = 2L$ (m), as explained by [3]. As suggested by Fang [4], it is convenient to adopt the power law equation to study the velocity profile $v(r)$ (m/s) in the cross section of a circular duct as

$$\frac{v(r)}{v_c} = \left(1 - \frac{2r}{D_h}\right)^{1/n} \tag{2}$$

where r (m) is the radial coordinate, and n (-) the power law coefficient calculated as follows [4]

$$n = -1.7 + 1.8 \ \ln Re \tag{3}$$

This equation is valid for Reynolds number at the center of the duct, Re (-), larger than $2 \cdot 10^4$. The mean velocities v_m are determined from the measured velocities at the center of the duct v_c as follows

$$v_m = v_c \frac{2n^2}{(n+1)(2n+1)} \tag{4}$$

In the final turn, the mass flow rate can be calculated for the samplings coupling Eqs. (1) and (4).

Finally, the exhaust humidity is estimated approximately assuming an initial quantity of water in the wet fabric being released constantly during the drying process. Specifically, the water content before drying is taken equal to 40% of the dry fabric, according to laundry experience. Then, the absolute humidity is estimated as the ratio between the mean evaporated water from the fabrics and the mean exhaust air mass flow rate.

2.3. Uncertainties

The relative uncertainties of temperature and velocity u_T (-) and u_v (-), respectively, are calculated according to the measurement uncertainties reported in the anemometer manual, as anticipated in the previous paragraph. In particular, the relative uncertainty on the mean velocity is equal to that of the center duct velocity, because the uncertainty on the coefficient n is neglected. For each sampling, the temperature and velocity uncertainties are calculated as

$$u_T = \frac{0.5}{T} + 0.003 \tag{5}$$

$$u_v = \frac{0.2}{v} + 0.015 \tag{6}$$

In its turn, the combined uncertainty of the mass flow rate u_m (-) is calculated according to [5]. In the present work, the temperature and the mean velocity are considered as the only sources of uncertainty. In contrast, the uncertainty of the frontal area A is considered negligible because it does not affect considerably the calculations.

In general, the calculation of the combined uncertainty U_f of a generic function f is as follows

$$\mathrm{U}_f = \sqrt{\sum_{i=1}^{n_{par}} \left[\frac{\partial f(x_i)}{\partial x_i} U_{x_i} \right]^2} \tag{7}$$

where n_{par} (-) is the number of parameters x on which the function f depends on. Thus, the absolute uncertainty of the mass flow rate U_m (kg/s) is calculated from Eq. (7) as

$$\mathrm{U}_m = \sqrt{\left(-\frac{M\,P}{R\,T^2} v_m A\, U_T\right)^2 + \left(\frac{M\,P}{R\,T} A\, U_v\right)^2} \tag{8}$$

where the temperature is expressed in K for sake of simplicity of writing. Multiplying and dividing the first term of Eq. (8) by v_m, and rearranging the equation, U_m becomes

$$\mathrm{U}_m = \sqrt{\left(-\frac{M\,P}{\mathcal{R}\,T} v_m A\,\frac{U_T}{T}\right)^2 + \left(\frac{M\,P}{\mathcal{R}\,T} v_m A\,\frac{U_v}{v_m}\right)^2} \tag{9}$$

Finally, explicating the mass flow rate definition and rearranging the equation, Eq. (9) becomes

$$\frac{\mathrm{U}_m}{\dot{m}} = \sqrt{\left(\frac{U_T}{T}\right)^2 + \left(\frac{U_v}{v_m}\right)^2} \tag{10}$$

All the fractions in Eq. (10) are equivalent to relative uncertainties. This means that the combined relative uncertainty of the mass flow rate can be easily calculated from the relative uncertainties of temperature and velocity as follows

$$u_m = \sqrt{u_{\mathrm{T}}{}^2 + u_{\mathrm{v}}{}^2} \tag{11}$$

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships which have, or could be perceived to have, influenced the work reported in this article.

Acknowledgments

The authors acknowledge gratefully Lavanderia Borromeo S.r.l. for giving the opportunity and the time to record the measurements and to discuss the results.

Supplementary Materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.dib.2020.106323.

References

[1] G. Valenti, C. Bonacina, A. Bamoshmoosh, Optimal cascade phase change regenerator for waste heat recovery in a batch industrial dryer, Case Stud. Therm. Eng. 22 (2020).
[2] F.P. Incropera, D.P. Dewitt, T. Bergman, A.S. Lavine, Fundamentals of Heat and Mass Transfer, John Wiley & Sons, U.S.A., 2006.
[3] W.M. Rosenow, J.P. Hartnett, Y.I. Cho, Handbook of Heat Transfer, The McGraw-Hill Companies, New York, 1998.
[4] C. Fang, An Introduction to Fluid Mechanics, Springer, Switzerland, 2019.
[5] E.O. Doebelin, Strumenti e metodi di misura, McGraw-Hill Companies, Milano, 2008.