# The Influence of Gas Parameters on the Results of Spirometric Test

**B. Juroszek**

Division of Biomedical Engineering and Metrology
Faculty of Fundamental Problems of Technology, Wrocław University of Technology
Smoluchowskiego 19 str, 50 – 370 Wrocław, Poland
Email: barbara@pwr.wroc.pl

***Abstract.*** *The author presents a metrological analysis of the influence of the expiratory gas physical features on the preciseness of the parameters defined during lung tests. Two kinds of spirometric transducers are taken into consideration: a volumetric transducer and a flowmeter. When a volumetric transducer is used, the gas inside changes its temperature and a special correction is necessary; moreover, its value depends on time. When a flowmeter is used the expired gas is measured before its temperature becomes substantially lower and a correction factor shouldn't be the same as for a volumetric transducer. The problems are theoretically analysed and experimentally confirmed here.*

*Keywords: spirometric transducers, measuring conditions, measuring errors*

## 1. Introduction

The respiratory gas existing in the lungs (in so called *BTPS* conditions) is warm, having a body temperature of +37°C, water saturated. Expired outside, into actual temperature and pressure (called *ATPS* conditions), it cools down. Because of the fact, that outside conditions always change, normalization is applied, giving expiratory parameters for all patients in the same, *BTPS* conditions. When not to do such correction it appears an error.
Gas being inside the lungs having volume $V_{BTPS}$ is defined as

$$V_{BTPS} = V_{ATPS} \; \frac{310}{273+T_a} \; \frac{P_B - P_{H_2O}}{P_B - 6.26} \tag{1}$$

A conversion coefficient $K_K$ is:

$$K_K = \frac{V_{BTPS}}{V_{ATPS}} \tag{2}$$

where $V_{BTBS}$, $V_{ATPS}$ – gas volume measured in different conditions, $P_B$ [kPa] – ambient pressure, $P_{H_2O}$ [kPa] – water vapour pressure at ambient temperature $T_a$. The coefficient $K_K$ diminishes when ambient temperature and atmospheric pressure grow. The biggest influence on the accuracy is shown by ambient temperature $T_a$. Atmospheric pressure $P_B$ can be neglected (Fig. 1). When gas is measured far from mouth it cools, having almost ambient temperature; measured near the mouth, it doesn't cool [1].

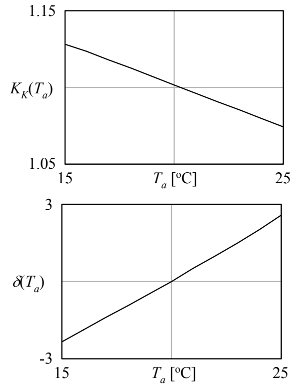


Fig. 1. Coefficient $K_K$ as a function of ambient temperature and its relative changeability $\delta$

## 2. Bell Transducer – the Temperature Influence

During forced expiration, which usually persists for about 6 seconds measured gas changes its temperature. Different expiratory parameters are measured in this time: $FEV_{0.5}$, $FEV_1$, $FEV_2$, $FEV_3$ and the same value conversion coefficient $K_K$ used creates an extra error, with a different value, dependently on the kind of expiratory parameters (0 to 6 seconds). When to assume that in forced expiration, measured gas volume changes in an exponential manner [2], the gas temperature in the bell is changing in similar way (Fig. 2.ab and Fig. 3.ad) and the conversion coefficient changes its value. When to neglect this fact such changes it appears an error (Fig. 2.cd and Fig. 3.ef).

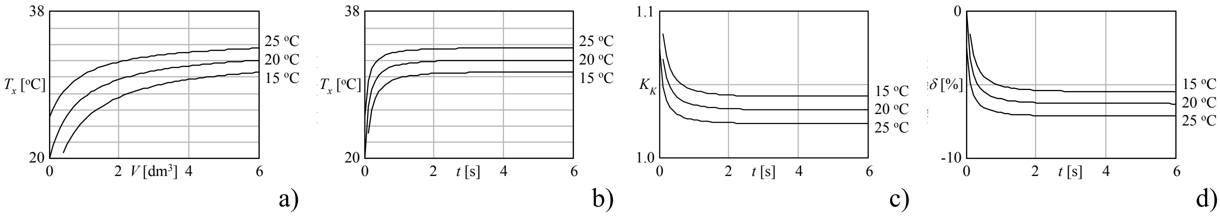


Fig. 2. The temperature changes $T_x$ in the bell during forced expiration (gas temperature at its input +37°C for ambient temperature +15 °C, +20 °C, +25°C: a) – the temperature changes in the bell, b) – the temperature changes over time, c) – conversion coefficient changes, d) – the error, when to neglect the temperature influence (in relation to $K_K$ ($T_a$ = +20°C) = 1.102))

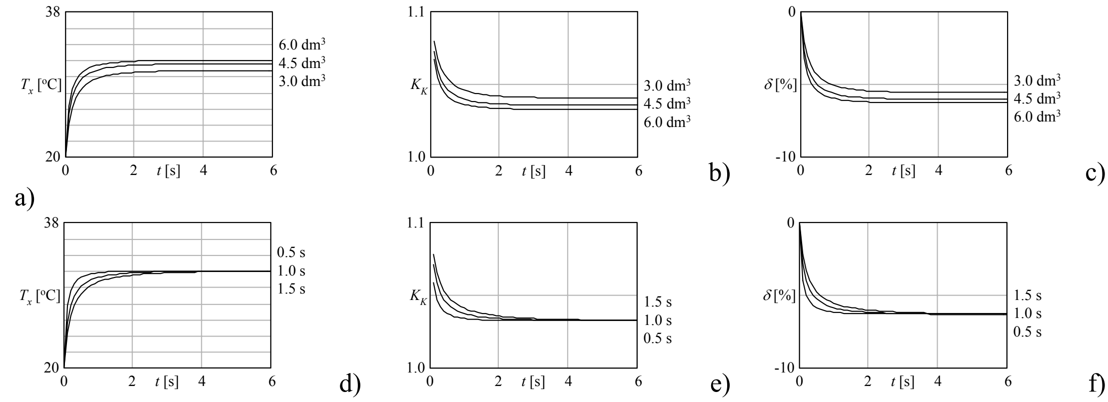


Fig. 3. The influence of some respiratory system parameters: forced vital capacity $FVC$ (a, b, c) and time delay $\tau$ (d, e, f), on physical conditions in the bell and resulting errors

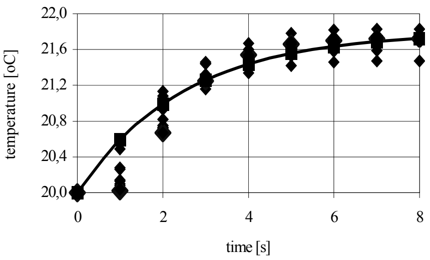


Fig. 4. The temperature changes inside the dry bell when a warm gas ($T$ = +37°C) is going into it during ten forced expirations for one patient ($FVC$ = 3.5 dm³)

Confirmation of the above theoretical considerations are the measurements (Fig. 4), where one patient exhaled gas into a dry volumetric spirometer. The transducer was made in the form of a closed gum "sleeve". Gas coming inside induced movement of the upper metal "sleeve" cover. Ambient temperature was +20°C. The ini-tial gas volume in the bell was almost zero. The healthy patient made some forced expirations; $FVC = 3.5$ dm$^3$. Because the bell was heated by exhaled gas, the next expiration started when it reached ambient temperature (+20°C). The gas temperature reaches exponentially and at the end of expiration is neither ambient nor the patient's, but it is about 2°C higher than ambient. It means that such a temperature gives an error of 1 % ($K_K = 1.102$ for +20°C and $K_K = 1.091$ for +22°C).

### 3. The Measurements with Using Flow Transducer

The experiments were made with two transducers: turbine and Fleisch tube. The turbine transducer had a plastic housing. The Fleisch transducer, with a metal housing (a screen was flow resistance) with an initial temperature $T_a$ and then was the purposefully heated to about +41°C. In every case the patient made forced expiration into transducer and at that time the maximal temperature of exhaled gas in steady-state conditions in transducer output was measured (Table 1 and Table 2). The results show, that when flow transducers are used the temperature of exhaled gas changes, but it doesn't cool to ambient temperature. When the transducer screen is heated the temperature of ex-haled gas practically doesn't change.

Flowing gas is characterized by the viscosity $\nu_p$ whose value depends on gas vaporization (dry – inspired gas, water vaporized – expired) and its temperature [3].

Table 1. The temperature of gas exhaled into spirometric transducers during forced expiration

| No. | Inlet temperature (in mouth) [°C] | Outlet temperature of transducer [°C] | | |
|---|---|---|---|---|
| | | Turbine | Fleisch not heated | Fleisch heated |
| 1. | 34.2 | 32.4 | 34.2 | 36.0 |
| 2. | 34.5 | 33.1 | 33.6 | 36.3 |
| 3. | 33.8 | 33.4 | 33.7 | 36.3 |
| Mean | 34.17 | 32.97 | 33.83 | 36.20 |

Table 2. Comparison of conversion coefficient $K_K$ value for different kinds of spirometric transducers; $T_a$ = +20°C

| Measuring conditions | | Kind of transducer | | | | Steady-state values according to eq. (1) |
|---|---|---|---|---|---|---|
| | | Flow transducers | | | Volumetric | |
| | | Turbine with plastic housing | Fleisch tube with metal housing | | Bell | |
| | | | Not heated | Heated | | |
| Gas temperature [°C] | | 35.0 | 34.0 | 36.6 | 21.8 | 22.0 |
| $K_K$ | | 1.014 | 1.020 | 1.003 | 1.093 | 1.092 |
| $\delta$* [%] | $K_K$ = 1 | -1.4 | -2.0 | -0.3 | 8.5 | – |
| | $K_K$ = 1.092 | 7.7 | 7.1 | 8.9 | -0.1 | – |

* relative error of $K_K$ definition, misassumed like $K_K$ = 1 (i.e. without taking into account external temperature conditions) or $K_K$ = 1.092

During spirometric measurements it is possible to meet six different measuring situations:
a) cold transducer, at ambient temperature, is calibrated. After sometime the patient is measured. It means, that the calibration and the patient' measurement are made at that same temperature (ambient);
b) cold transducer, at ambient temperature, is calibrated. Afterwards the patient makes some trials, warming the transducer incidentally, then he makes the final ("measuring") expiration;
c) after the transducers use by a patient it becomes warmer, then it is calibrated and then the patient is measured. It means, that the calibration and the measurement are made at the same, a little higher than ambient, temperature;
d) the transducer is heated purposefully (here: to +40°C).Calibrating procedure and patient' measurement are made at the same, high temperature;
e) the purposefully heated transducer is calibrated. A patient makes some trials, cooling it a little. Then he does the final test;
f) after frequent use the purposefully heated transducer (by a patient) it becomes a little cooled it is then calibrated. Then the patient does his test.

The first three cases (a, b, c) concern a cold transducer. Sometimes its temperature rises as a result of warm gas, that flows through it (cases b, c). The last three cases (d, e, f) concern a transducer which is purposefully heated. Here the warm transducer can be cooled as a result of the patient's gas flowing through it (cases e, f). Calibration in the four different situations needs to be considered under different thermal conditions. The spirometer calibrated using 1dm$^3$ gas volume really registers another gas volume. It depends on the temperature of expired gas, ambient temperature $T_a$ and transducer temperature, that was heated to $T_g$ temperature the purposefully or incidentally by the previous patient. When to consider the changes of gas viscosity as results of the temperature and the kind of gas (expired or inspired) the gas volume should be corrected by using factor

$$K_L = \frac{\nu_{p\ ex\ Tg}}{\nu_{p\ in\ Tg}} \frac{273+T_a}{273+T_g} K_{K\ Tg} \tag{3}$$

where $\nu_{p\,ex\,Tg}$, $\nu_{p\,in\,Tg}$ – inspired or expired gas viscosity, respectively, when its temperature is $T_g$, $T_a$ – ambient temperature, $K_{K\,Tg}$ – conversion coefficient calculated for the temperature $T_g$.

The experiments presented in Table 3 show that when the patient exhales gas several times (in experiment conditions this temperature was +22°C), in the output of spirometric transducer the temperature is + 33.4°C. When the transducer is the purposefully heated (in experiment conditions this temperature was +37°C) by gas particles movement it falls to +36.6°C. The temperature changes depend on the kind of gas (inspired or expired) and its viscosity which changes too. In consequence it can be a source of substantial measuring errors.

Table 3. The parameters of expired gas volume and appearing errors, $T_a$ = +22°C

| Measuring case | | a | b | c | d | e | f |
|---|---|---|---|---|---|---|---|
| Calibration temperature | | 22.0 | 22.0 | 33.8 | 40.0 | 40.0 | 36.2 |
| Measuring temperature | | 22.0 | 33.8 | 33.8 | 40.0 | 36.2 | 36.2 |
| Patient' testing | $K_K$ | 1.091 | 1.021 | 1.021 | 0.979 | 1.006 | 1.006 |
| | $\nu_{inspiration}$ | 182.29 | 186.76 | 186.76 | 188.79 | 187.55 | 187.55 |
| | $\nu_{expiration}$ | 178.24 | 181.63 | 181.63 | 182.80 | 182.09 | 182.09 |
| | 1dm$^3$ in transducer | 0.9166 | 0.9615 | 0.9615 | 0.9425 | 0.9425 | 0.9542 |
| | Combined effect | 0.8962 | 0.9158 | 0.9350 | 0.9126 | 0.9095 | 0.9264 |
| | After *BTPS* correction | 0.9778 | 0.9350 | 0.9546 | 0.8934 | 0.9150 | 0.9320 |
| | $\delta V^{(1)}$ [%] | -2.2 | -6.5 | -4.5 | -10.6 | -8.5 | -6.8 |
| Transducer calibration | $\nu_{calibration}$ | 182.29 | 182.29 | 186.76 | 188.79 | 187.55 | 187.55 |
| | $\nu_{measurement}$ | 178.24 | 181.63 | 181.63 | 182.80 | 182.09 | 182.09 |
| $\delta V_R^{(2)}$ [%] | | 2.3 | 0.4 | 2.8 | 3.3 | 3.0 | 3.0 |
| $\delta V + \delta V_R$ | | +0.1 | -6.1 | -1.7 | -7.3 | -5.5 | -3.8 |

Remarks: error $^{(1)}$ – concerns definition of amount of expired gas volume; error $^{(2)}$ – concerns the changes of transducer's flow resistance resulting from gas viscosity.

## 4. Results

The conditions of the spirometric measurements depend to a different degree on both gas features and the surroundings. The conversion coefficient $K_K$ allows for all these influences. The most substantial influence is ambient temperature $T_a$, which is almost always lower than the temperature of expired gas.

When a bell transducer is used in spirometry the conversion coefficient $K_K$ is a function of the time. The temperature influences can be avoided when the flow type spirometric transducer is used. The purposefully heated reducing pipe gives stabilization of thermal conditions of spirometric measurements and prevents water vapour molecule deposition on its wall (on capillaries or strainer). When one patient is tested independently of others (he doesn't take part in a group test) it is better to use an unheated spirometric transducer, because the temperature influence shows a lower error.

## References

[1] Madan I., Bright P., Miller M. R.: Expired air temperature ay the mouth during a maximal forced expiratory manouvre, *European Respiratory Journal* 1993, 6 (7): 1556–1562.

[2] Khoo M. C.: Physiological control systems. Analysis, simulation and estimation, IEEE Press, New York, 2000.

[3] Quanjer P. H., Tammeling G. J., Cotes J. E., Pedersen O. F., Peslin R., Yernault J. C.: Lung volumes and forced ventilatory flows, *European Respiratory Journal* 1993, 6 (s 16): 5–40.