Comparison of Exhaled Molar Mass and CO_2 Curves

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Introduction

Ultrasonic gas flow sensors are commonly used in medical applications. In addition to flow this sensor technology can be used to simultaneously determine flow/volume and molar mass (MM) of the gas. Exhaled MM vs. exhaled volume curves are compared to conventional capnography using an infrared CO_2 sensor (irCO_2).

Methods

Two flow/MM sensors (Spiroson, ndd, Switzerland) and a side stream irCO_2 sensor (Welch Allyn, USA) are used. Flow, volume, MM and CO_2 are sampled at 200 Hz. One flow/MM sensor is used in main-stream the other in side-stream arrangement. Ultrasonic flow/MM data is based on transit-time measurement of pulse trains traveling up- and downstream the gas flow. Flow F and MM can be determined by the following equations:

$$F = k_1 \frac{t_u - t_d}{t_u \cdot t_d}; \qquad MM = k_2 \cdot \kappa \cdot R \cdot T \left(\frac{t_u \cdot t_d}{t_u + t_d} \right)^2$$

F depends on mechanical dimensions (k_1 is given by the distance between transducers and flow tube diameter) and on transit-times t_u, t_d; F is independent of gas temperature, pressure and gas composition.

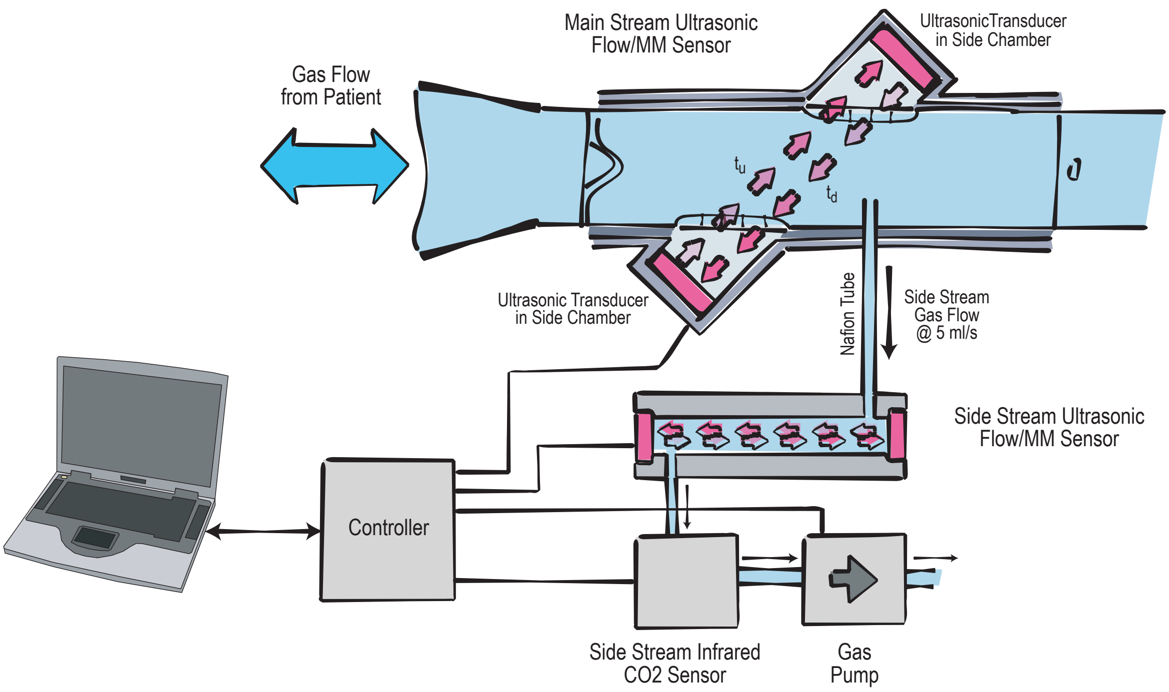
MM depends on mechanical dimensions (constant k_2), gas properties, temperature T and transit-times t_u, t_d.

Due to the mechanical construction of the mainstream ultrasonic flow/MM sensor only 55% of the sound transmission path is within the flow tube; the remaining 45% is within the side chambers in front of the ultrasonic transducers.

Therefore the MM measurement must be subdivided in two parts: Side chamber MM and flow tube MM. In addition temperature in the side chamber also differs from temperature in the flow tube. Comparison of main- and side-stream MM allows differen-- tiating temperature and diffusion effects caused by the side chambers.

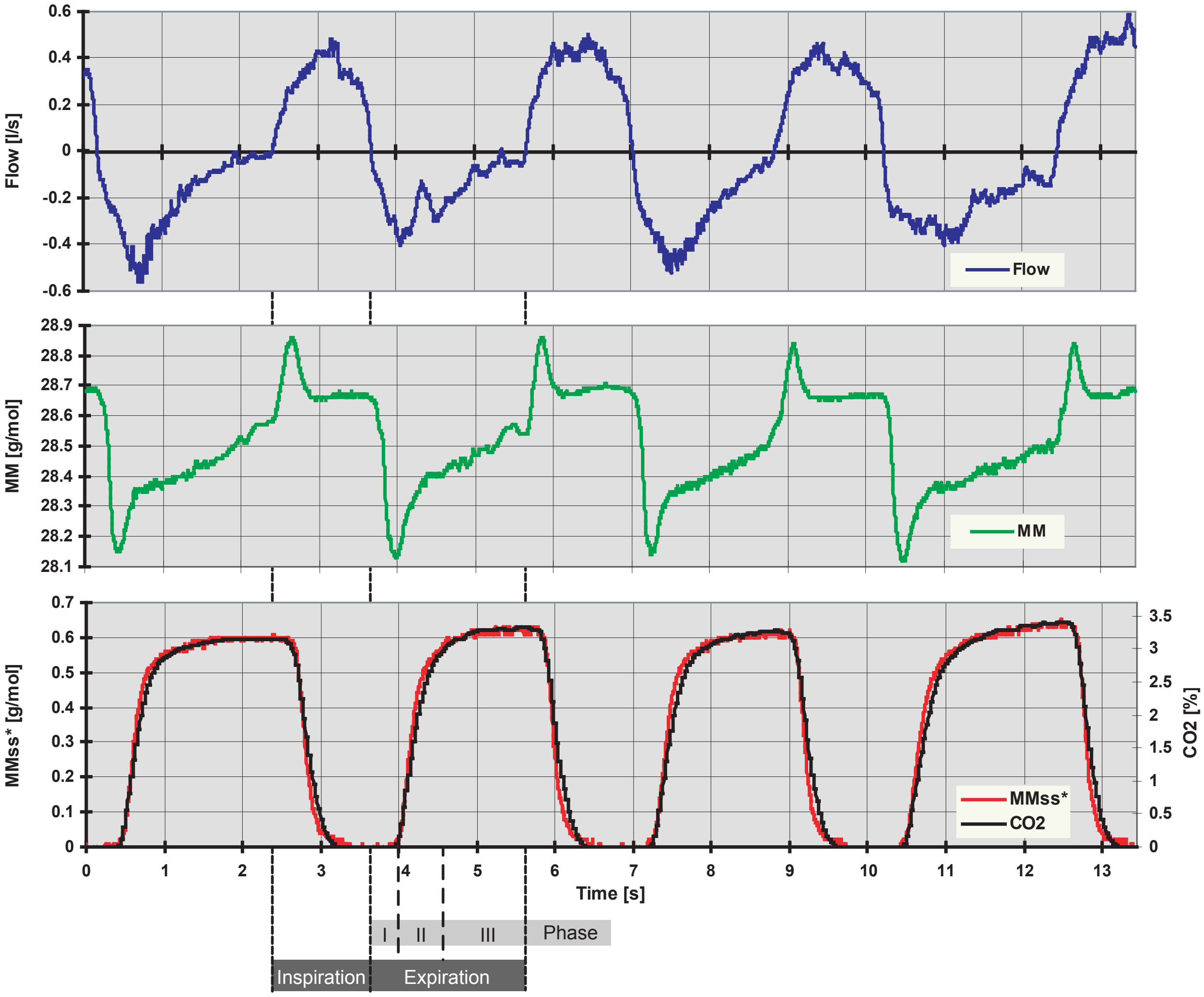
Both ultrasonic flow/MM sensors, the irCO_2 sensor and the side stream gas pump are connected to a controller that samples the data and transmits it to a PC using WBreath data acquisition software (ndd, Switzerland). A Nafion tube is used to reduce water vapor in the side stream.

The following block diagram shows the test setup:



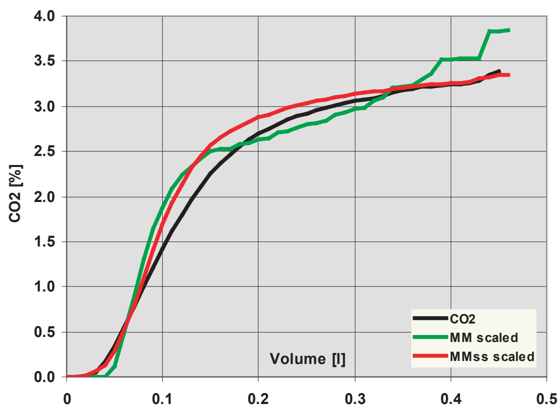
Results

The following diagram shows 4 breaths of flow, main stream MM, side stream molar mass MMss* (with offset correction) and CO_2 from the $irCO_2$ sensor during quiet breathing of a healthy subject.



Since flow and MM are derived from the same transit-time measurement, no delay correction is necessary. The signals of CO_2 and MMss* are side stream signals and have been delay corrected. After that correction the signals of CO_2 and MMss* are very similar in both shape and amplitude. The expiratory phases I, II and III can clearly be identified.

Resolution of MM is approx. 0.01 g/mol corresponding to approx. 0.05% CO_2, response time of MMss* is approx. 100 ms.

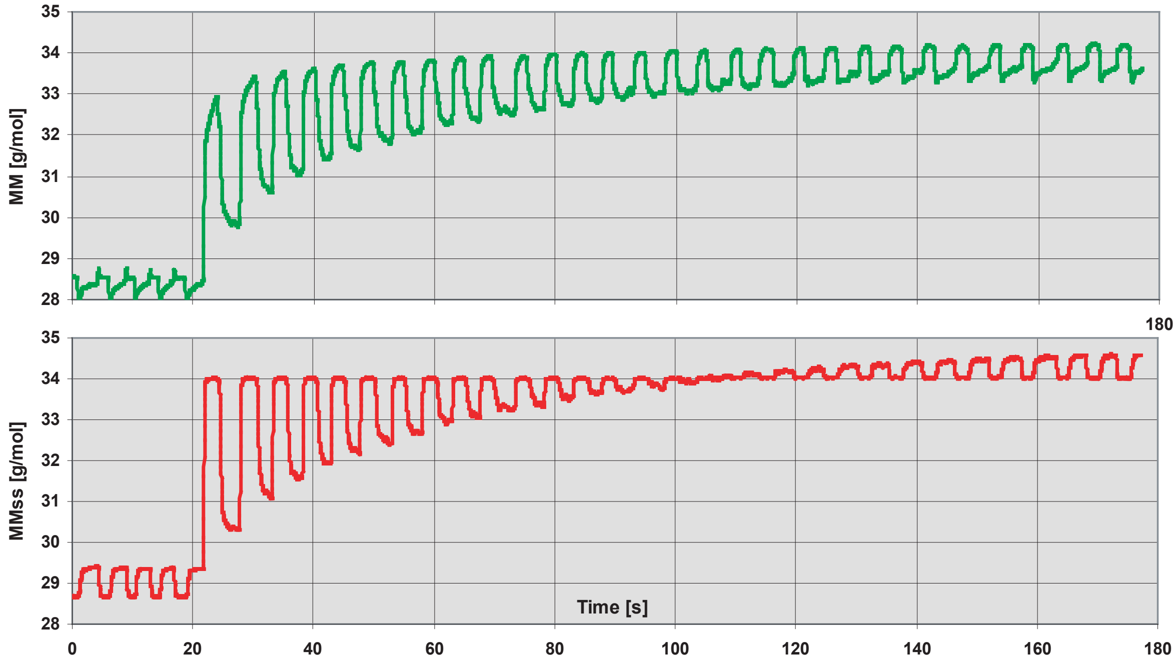


The diagram on the left shows the expirograms of CO_2, MM and MMss vs. expired volume. The curves are averaged curves computed from approx. 30 breaths of quiet breathing.

CO_2 shows the slowest response, followed by MMss. Main stream MM shows the fastest response, however, the signal is influenced by temperature and diffusion effects, clearly visible at the end of the alveolar plateau.

Diffusion effects can be seen more clearly when performing FRC measurements with a tracer gas.

The following two diagrams show the signals of main stream and side stream MM during a tracer washin procedure used for FRC measurement. The tracer is 4% SF6, resulting in a molar mass step of approx. 5.5 g/mol.



The main stream MM is influenced by the following components:

1) In/expiratory temperature differences: A temperature change from 20 to 37 degC (room air to expiration) corresponds to a MM change of approx. 1.7 g/mol.
2) In/expiratory humidity differences: A humidity change from 40% at 20 degC to 100% at 37 degC, corresponds to an MM change of approx. 0.58 g/mol. The influence of humidity can clearly be seen from the tidal breathing measurement where MM decreases quickly at the beginning of the expiration.
3) Diffusion of gas to and from the side chambers of the ultrasonic flow sensors: The time constant of the diffusion depends on the gases used. The diffusion effect can be approximated by an exponential exchange between flow tube and side chamber. The effect can result in MM changes up to 2 g/mol.

The above mentioned influences are large considering the MM resolution of 0.01 g/mol.

In the side stream arrangement, on the other hand, temperature of the gas is very stable, side chambers and therefore diffusion do not exist, and humidity is also held constant by using the Nafion tube.

Conclusion

The side stream MM sensor can be used to substitute conventional capnography in the case of tidal breathing measurements. Its performance in clinical application and the use of uncorrected main-stream MM for tidal breathing analysis is currently further investigated.

Side stream as well as main stream molar mass measurements can both be used for the measurement of FRC using tracer gas washin/washout procedures. In the case of main stream MM temperature and diffusion effects must be corrected by mathematical models. Accuracy of both methods will be further investigated in clinical studies.

Acknowledgement

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