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Model enhanced paperboard permeability measurement with aerostatically sealed non-contacting instrument

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Abstract

Paperboard permeability is a crucial quality parameter for various grades of paper and cardboard. Traditionally, the permeability measurements are conducted offline using contacting devices. The present study delved into a non-contact aerostatically sealed measurement method and device.

The investigated method, previously developed by the authors, was improved by introducing an aerostatic seal flow model into the calculation of sample permeability. This flow model enables the calculation of seal exhaust into the measurement volume, directly influencing the measured flow through the sample. The method was compared to a reference measurement with contacting seals and to the simple method of the previous study.

The results show that the improved method has good accuracy. Furthermore, the influence of seal supply pressure is found to be negligible. Thus, the study provides evidence on the feasibility of the measurement method and device.

Aerostatic bearing, aerostatic seal, in-process measurement, aerostatic seal model

1. Introduction

Paperboard permeability is crucial quality parameter for various paper and cardboard grades, including applications in filter and packaging materials. Furthermore, permeability is closely related to porosity, which is also a quality parameter of interest.

Permeability measurement methods, such as the Bentsen method standardized in ISO 8791-2:2013 [1], typically involve generating a pressure difference across the investigated sample and measuring the flow through it [2, 3]. The maximum feasible pressure difference is limited by the strength of the sample. Therefore, some measurement devices use wire meshes or grids to support the sample, allowing for the application of higher pressure differences [4, 5].

Permeability measurement with a non-contacting method has significant benefits over the contacting methods, one of the most important being the possibility to measure continuously from a fast moving web. This allows online measurement during roll-to-roll processing, while the conventional methods necessitate offline measurements with samples cut from the web.

The present study improves upon previous studies, in which first a two-sided aerostatically sealed measurement device was introduced [6], and later an improved single sided device better suited for online measurements was presented [7]. The current study further enhances these advancements by introducing a seal flow model to the permeability calculation. The flow model establishes a connection between the measured flow rates and the permeability of the sample.

2. Methods

The investigated device consists of porous aerostatic bearing elements, a measurement volume, and a vacuum groove (Figure 1). The vacuum groove is used to preload the measured sample against the aerostatic bearing elements, establishing a seal around the measurement volume. The measurement volume is an 8.2 mm wide and 30 mm long slot. Instrumentation of the seal supply and vacuum connections included flow and pressure sensors. Additionally, the gap height between the sample and the device was measured with a triangulating laser sensor. The measurement setup is presented in Figure 2.

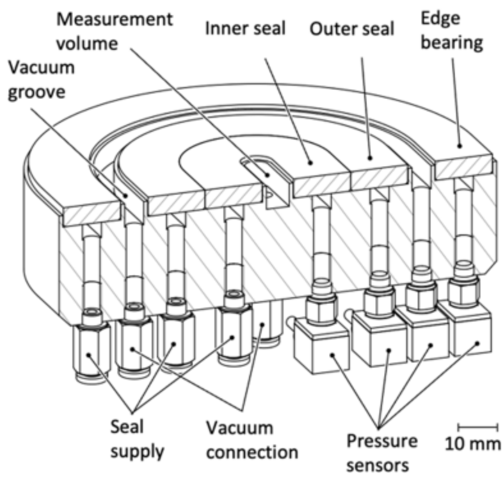

Figure 1. Cross-section of the measurement device.

Tests were conducted with a pressure difference of 1.47 kPa across the paper sample, which is the same pressure difference as in the conventional Bentsen method. The seal supply pressure was varied in the range of 0.15 MPa to 0.25 MPa. Reference tests were conducted with a 31.5 mm diameter measurement area device, that clamped both sides of the sample and sealed with o-rings.

The paper samples used were ordinary printing paper, referred to as sample 1, and coated paper with lower permeability, referred to as sample 2.

Furthermore, the improved calculation method with the flow model was compared to the simpler method utilized in the previous study [6]. In the simpler method, it was assumed that exactly all of the inner seal exhaust flowed into the measurement volume.

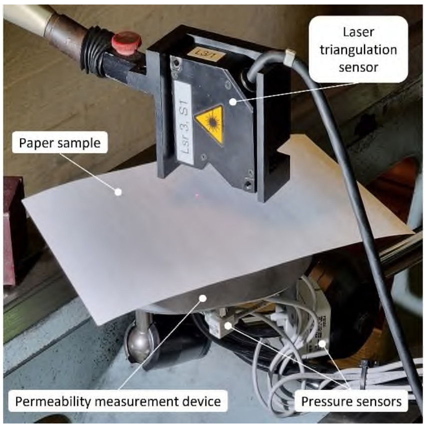

Figure 2. Measurement setup. The laser used in the gap height measurements is positioned between the inner and outer seal elements. [6]

In the flow model, a simplified porosity model was used, assuming unidirectional flow in the restrictor. Furthermore, the opposing surface of the seal was considered impermeable. The flow model is based on the well-known modified Reynolds equation for aerostatic bearings [8, 9]:

$$\nabla \cdot (ph^3 \nabla p) = -\sqrt{\frac{12k_\mathrm{P}}{h_\mathrm{P}}}(p_\mathrm{S}^2 - p^2)$$

where p is the pressure in the air gap, p_S is the supply pressure, h is the air gap height, k_P is the permeability and h_P is the height of the restrictor.

The boundary conditions of the model, i.e., the supply pressure, pressures in the measurement chamber and vacuum groove, and the gap height, were measured. The model was then used to calculate the flow into the measurement volume. Consequently, the permeability of the paper sheet could be calculated from the measured flow out of the measurement volume and the calculated flow from the seal into the volume:

$$\mathrm{Q} = k_\mathrm{Q}(Q_\mathrm{MV} - Q_\mathrm{SE})$$

where Q is the flow through the sheet (comparable to the Bentsen method), k_Q is an empirically determined coefficient, Q_MV is measured flow out of the measurement volume and Q_SE is calculated seal exhaust into the measurement volume.

3. Results

The measured permeability values for samples 1 and 2 are shown in Figure 3.

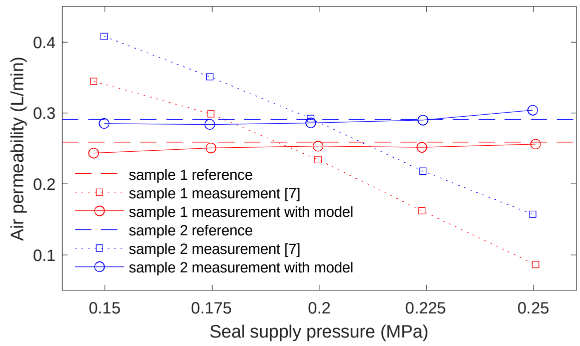

Figure 3. Air permeability of the investigated samples. Measurement [7] is with simpler method, measurement with model is with the improved method and reference value is measured with O-ring seals.

4. Discussion

The findings of this study show that the improved method with the seal flow model significantly improves the accuracy of the measurement in comparison to the simple method of the previous study. Notably, the improved method negated the influence of the seal supply pressure on the measurement result.

The simplifications of the model required the use of an empirically determined coefficient on the flow, k_Q = 0.5. The authors hypothesize that this coefficient may be necessary due to the assumption of the impermeable opposing surface for the seal, while in reality there is flow through the sample. Another potential cause changing the flow behaviour is the deformation of the sample resulting in non-uniform gap height.

Further studies could improve the flow model by implementing a permeable opposing surface for the seal, potentially removing the need for heuristic correction parameters. Furthermore, online measurements at low and high running speeds would be beneficial in further elucidating the method's efficacy.

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