

## Measurement of air content of pulp suspension – sonar method

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*Keywords: gas content, speed of sound, micro bubbles, macro bubbles*

### Abstract

Gases have negative effects on the production efficiency and the product quality. Both entrained and dissolved gases can be found from virtually all pulp flows, but fast and accurate inline measurement technique for gas content measurement has yet to be established. In these experiments new sonar technique for gas content measurement was tested.

Experiments were done in pilot-scale pumping system where pulp suspension was circulated with centrifugal pump in closed loop. Measurements were located in the vertical outlet pipe of the pump. Air content of the system could be adjusted with two different principles. Macro bubbles ( $\varnothing > 100 \mu\text{m}$ ) were fed to the system through membrane tube controlling volumetric air flow with rotameters. Micro bubbles ( $\varnothing = 20\text{-}100 \mu\text{m}$ ) were created precipitating bubbles from dissolved form controlling the level of dissolved oxygen and volumetric flow of the supersaturated suspension. Measurement accuracy of the sonar method was tested with four different air content levels and two different bubble types. Furthermore the effect pulp grade, consistency, flow velocity and process pressure were tested. Microwave and radiometric methods were used as reference measurements.

Results show that with sonar method accurate gas content result can be obtained independently on the pulp grade, process pressure, flow velocity or bubble size.

### Introduction

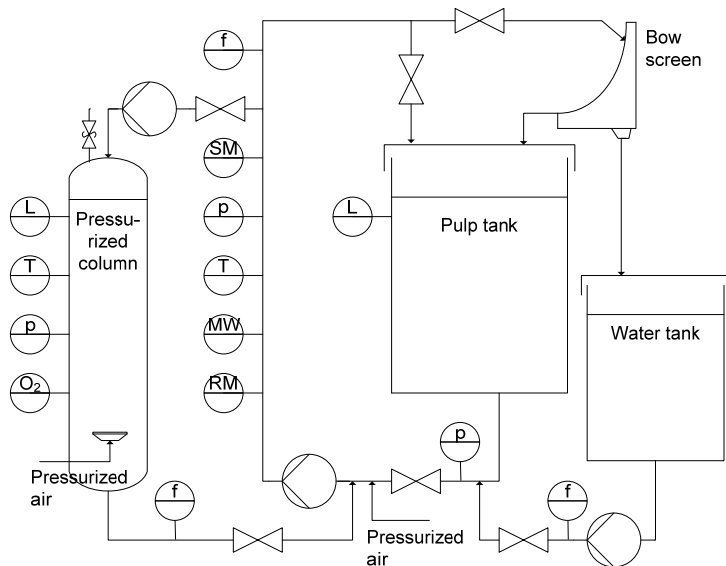
Pulp suspension practically in all pulping and papermaking unit processes contains gases either in dissolved form or as free gas bubbles. Gases can enter system with raw materials, process waters or directly from the atmosphere via leaking seals or open tanks. Dissolved gases do not disturb operation of unit operations or affect quality of the final product. Nevertheless, when conditions change dissolved gases can turn to gas bubbles, which decrease pumping efficiency, have negative effect on the accuracy of certain measurements and causes pinholes and specks on the paper web, for instance.

In order to observe and control the potential problems, reliable measurement of air content of pulp suspension must be available. Some offline measurement techniques are used, but fast and accurate inline measurement has remained to be a challenge for the pulp and paper industry. Earlier measurements in pulp mill processes have shown significant levels of entrained air, and also reasonable short-term variations in these levels (1) emphasising need for online gas content measurement device.

### Materials and methods

#### *Experimental setup*

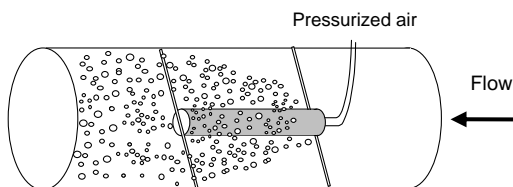
Experiments were carried out in a pumping loop, where the water was circulated by a centrifugal pump and gas content was measured in a vertical pipe (DN150) in the outlet of the pump (Fig 1.).



**Figure 1.** Experimental setup. SM denotes to sonar method, MW microwave measurement, RM radiometric measurement and O<sub>2</sub> measurement for dissolved oxygen. L stands for liquid level, T temperature, p pressure and f flow volume.

### Generation of air

Two different methods were used to adjust the air content in the loop. Macro bubbles were created feeding pressurized air through a sintered polyethylene tube, placed inside the inlet pipe of the centrifugal pump (Fig. 2). Volumetric air flow to the membrane tube was controlled with rotameters and was calculated to process pressure according to the Boyle's law ( $pV=\text{constant}$ ). Average bubble size created with this tube is typically 2.5 mm in the atmospheric pressure.



**Figure 2.** Creation of macro bubbles.

Micro bubbles were generated by precipitating air bubbles from supersaturated pulp suspension. Part of pulp suspension was pumped to pressurized column, where air was dissolved into suspension and when pressure was released with a control valve, micro bubbles were created. Pressure of the column was adjusted to 5 bars. For estimation of the volume of micro bubbles generated from dissolved form the amount dissolved oxygen in the column was measured with an electrochemical sensor and the volume of generated air calculated according to the Henry's law. Further the volume of air at the process pressure was calculated based on the Boyle's law and volumetric pulp flow from the column.

### Air content measurements

The air content in the outlet of the centrifugal pump was measured using new inline measurement method; sonar technique. Radiometric method and microwave method, that are applicable for air content measurement in controlled environment, were used as reference measurements.

Sonar measurement technique measures volumetric percent of entrained air in the pulp suspension. The amount of entrained air/gas is determined measuring the sound speed, or speed at which sound propagates, through the process medium. Measurement is based on patented array processing

techniques to listen to, and interpret acoustic fields generated by the machinery, piping and flow present in all industrial processes. The entrained air percentage is then calculated directly from the measured sound speed. (2)

Radiometric method is based on the attenuation of gamma radiation between a radioisotope source (Cs-137) and a sensor. The main interaction mechanism between the radiation and the material is Compton scattering. Each electron acts as a scattering target, and therefore the probability of each absorbing atom producing scattering increases linearly with the number of electrons in the medium. When the gas-free density of the suspension is known, the volume of gaseous components (V%) can be calculated based on the density variations.

Microwave method is based on the interaction between microwaves and an intermediate material. The basic principle is that a transmitter sends a beam of microwave rays through the process pipe to a receiver, and the time of propagation is measured. The time is dependent on the isoelectric properties of the media, which differs between the pulp components; fiber, water and gas. Thus the volume of gas can be calculated by measuring the traveling time if the proportions of fibers and water in the medium are known. Principle of microwave measurement was introduced by Jakkula (3) in his academic dissertation and further discussed by Virkkala et al. (4). In this study the air content of pulp suspension measured with microwave method is calculated based on the theoretical sensitivity of microwave that is 1.4 times higher with air than with fibers.

As the use of radiometric and microwave method for the measurement of air volume is based on the information of the air free properties of the pulp suspension at the measurement point, these properties must be determined by some other available method. In these tests the consistency of the suspension was measured in laboratory at the beginning and in the end of each test run. Air free test points were also carried out along the test run. Air free density was also determined in the beginning and in the end of each test run and with air free test points during experiments. Air free consistency and density in each test point were calculated from these results.

These requirements generate additional uncertainties to the measurement result, which must be taken to consideration when estimating the results of microwave and radiometric methods.

#### *Pulp types and test parameters*

The pulp types tested were refined hardwood kraft pulp (HWK), refined softwood kraft pulp (SWK), thermomechanical pulp (TMP), groundwood (GW) and fine paper furnish (FPF). The properties of these pulps are presented in Table 1.

**Table 1.** Pulp properties.

	HWK	SWK	TMP	GW	FPF
CSF [ml]	400	497	186	45	375
Ash content [%]	n/a	n/a	n/a	n/a	20.7
L(n) [mm]	0.6	0.9	1.4	0.2	0.7
L(l) [mm]	0.9	1.9	1.7	0.7	1.0
pH	7.1	7.5	6.6	6.3	7.7
Conductivity [mS/cm]	0.6	0.5	0.3	1.3	0.8

The consistency was varied from 0.5 to 3.5% (3 levels) and the flow velocity of the pulp from 1 to 2.5 m/s (20-50 L/s) (4 levels). Test pressures were from 1 to 3 bars (3 levels) and air content was varied between 0 to 3% (4 levels) according to the volumetric flow in NTP and the bubble size was either macro bubble or micro bubble. Due to process technical limitations full matrix of these test parameters could not be completed, but nevertheless about 250 test points are included in the results of each pulp type. With hardwood kraft pulp only two consistency levels with micro bubbles were carried out and with GW results of some measurement points were lost due to problems with electrical connections.

Operation parameters and measurement data was collected with frequency of 1 Hz and results of each test point was averaged from the period of 3 minutes.

To examine how the measurement result of sonar method was influenced, in addition to air content measured with reference methods, by other factors, statistical analysis using forward entering linear regression method (SPSS 12.0) was applied. Depended variable was air content measured with sonar method (%) and predictors were microwave and radiometric based air content (%), bubble type (micro/macro), pulp consistency (%), pressure (bar) and pulp flow (l/s).

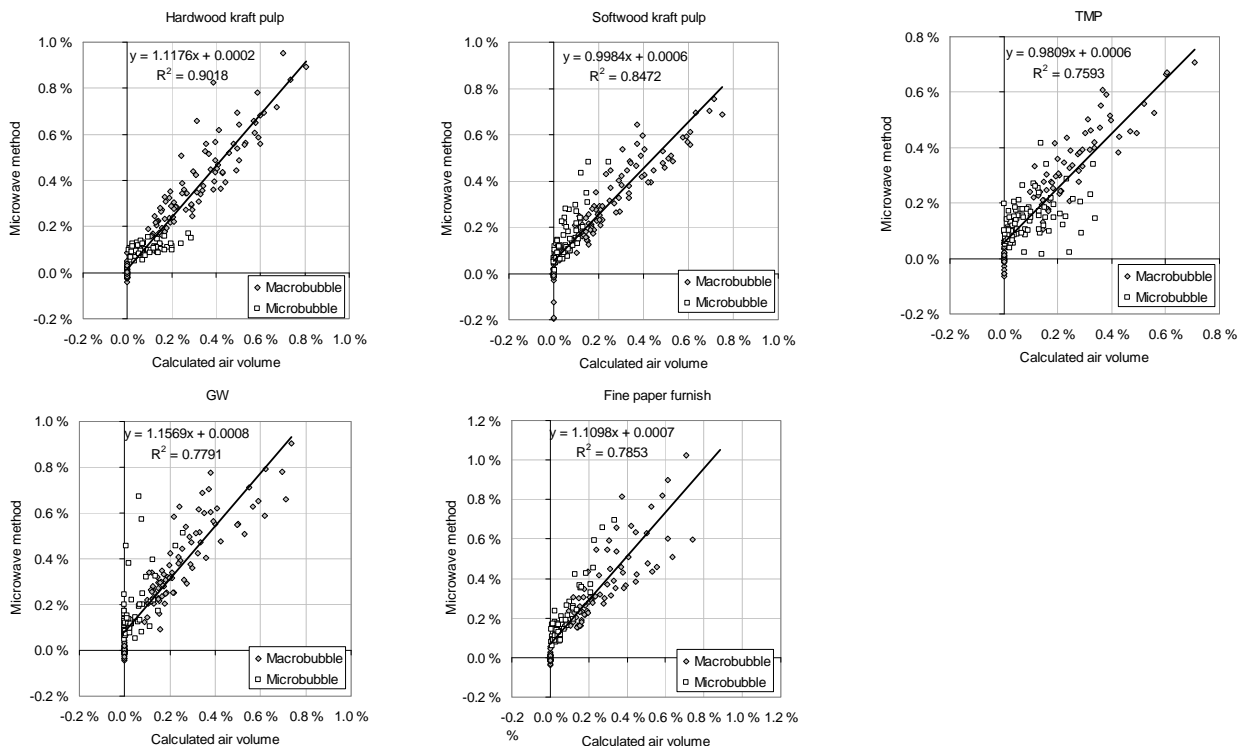
### Results and discussion

Evaluation of the results of the sonar method can be carried out comparing the output of the transmitter to the amount of fed air (macro bubbles) or calculated results from amount of dissolved oxygen (micro bubbles). Output of the sonar method can also be compared to the results of the microwave method or the radiometric method.

To determine, which is the best reference measurement method, results of the microwave method and the radiometric methods were compared to the amount of air at the measurement point.

#### Microwave method vs. air in feed

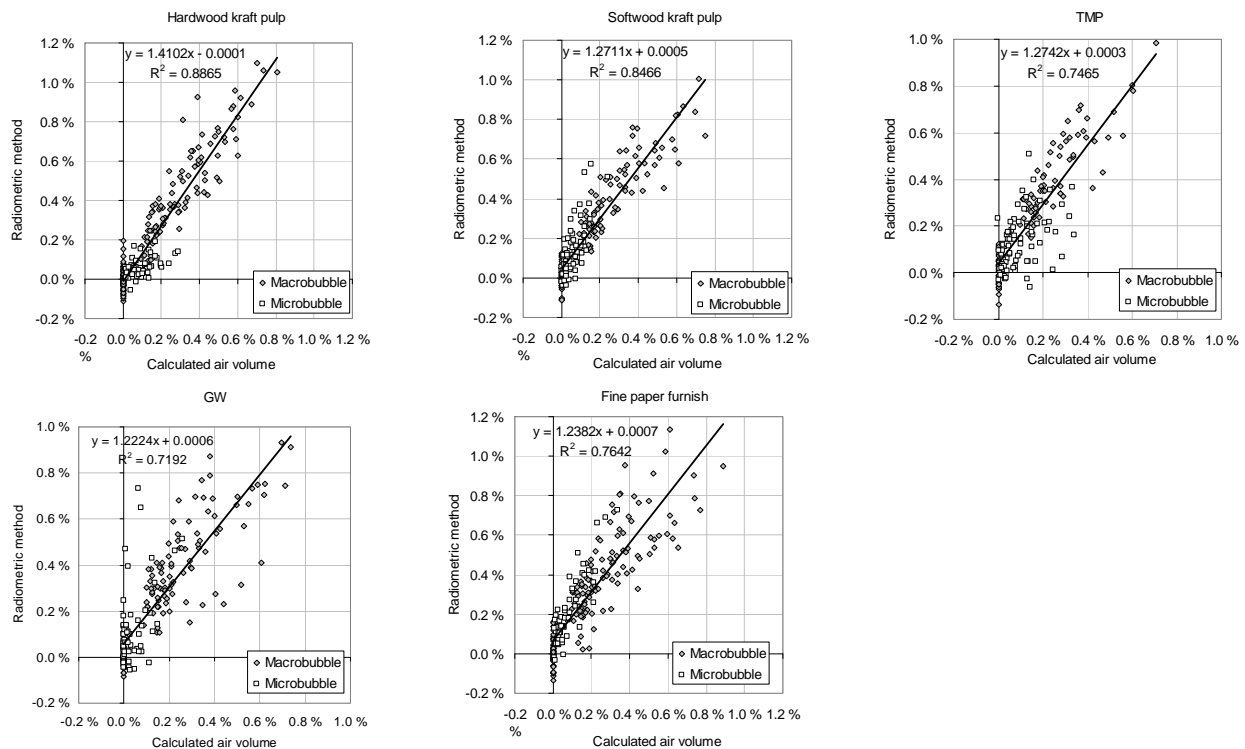
The correlation coefficients between the measurement result of the microwave method and the volume of air created to the loop was quite good (Fig. 3). The average correlation coefficient was 0.82. With SWK and TMP the slope of the correlation was approximately 1, but with HKW, GW and FPF the slope was over 1.1.



**Figure 3.** Microwave method vs. air in the feed. Linear regression line is presented for micro and macro bubbles combined.

#### Radiometric method vs. air in feed

The average coefficient correlation between the volume of fed air and the result of the radiometric method (Fig 4.) was somewhat lower than with the microwave method, 0.84 and average slope of the correlation 1.30. With HKW the slope was 1.42, but with other pulp grades between 1.22 and 1.28.



**Figure 4.** Radiometric method vs. air in the feed. Linear regression line is presented for micro and macro bubbles combined.

As with the microwave method, the air content measurement of the radiometric method requires air free test points and information of air free properties of the pulp suspension to determine the air volume. Unlike with the radiometric method, the information of the air free consistency that is needed to calculate air volume from the output of the microwave method can be obtained from laboratory analysis. This is less sensitive to analytical errors than determination of air free density that must be acquired with the radiometric density transmitter itself.

#### *Selection of reference measurement*

When evaluating sources of error in the measurement result in the volume of macro bubbles, there are several possibilities. Errors may derive from the actual measurement method, suitability of the method to the specific location; they may be originated from the inaccurate use of the rotameters or from the inaccuracy of the actual rotameters.

The estimation of volume of the precipitated micro bubbles based on the measurement of dissolved oxygen and volumetric flow from the pressurized column proved to be too inaccurate to obtain the actual air content. There are several uncertainties

As volume of micro bubbles in the measurement point is calculated based on the pressure in the measurement point and air volume in the flow from the column, where the of amount of dissolved oxygen, ideal gas law and estimation of dissolved oxygen after pressure release are used to calculate the volume of precipitated gas, it would be justifiable to make the conclusion that this is the main source of error.

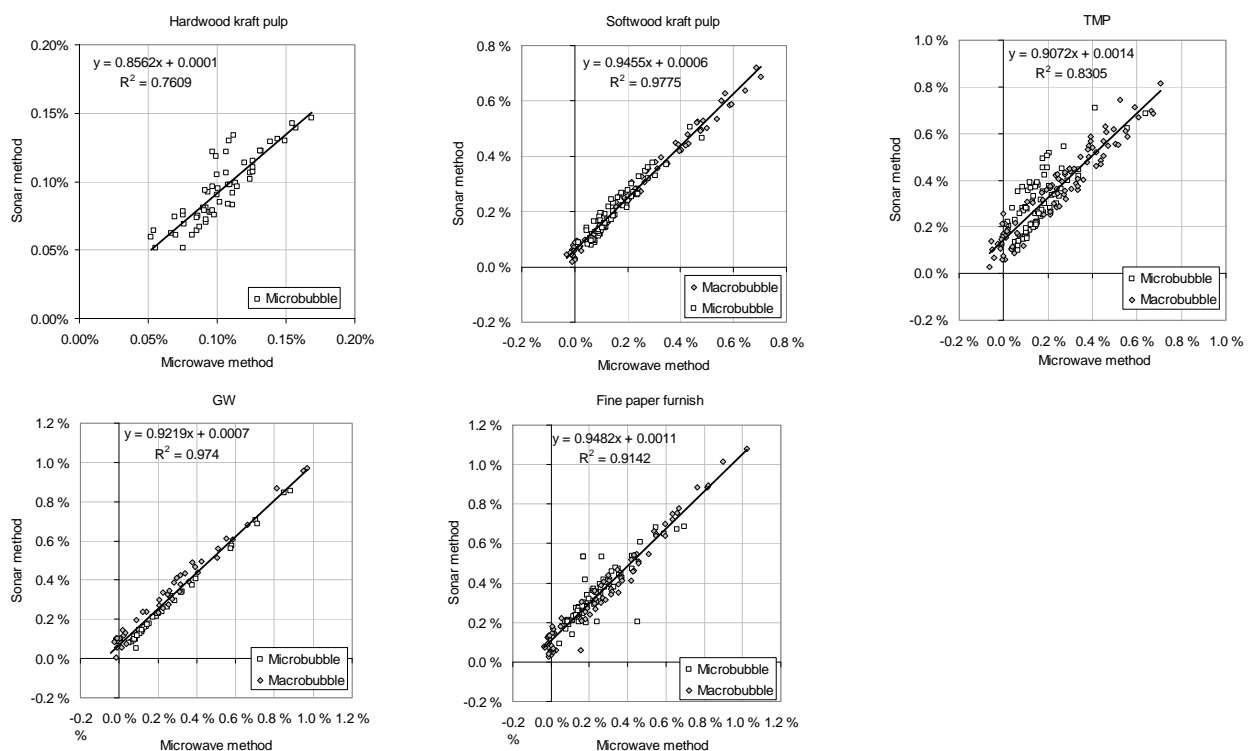
The calculation of air volume in the loop based on the volumetric air flow through rotameters, pulp flow from the column, pressure in the measurement point and from the amount of dissolved oxygen is too inaccurate to be used as reference method. Correlation coefficient of microwave method to calculated air volume is higher than that of radiometric method and proved to be the best reference measure method when evaluating the output of the sonar method.

## Sonar method vs. microwave method

The correlation of sonar method to microwave based air content measurement is presented in the Figure 5. The average slope of the correlation is 0.92 and the average correlation coefficient is 0.89. Air content measured with microwave is distinctly the most important predictor in the model. Pulp consistency has a minor increasing effect on with SFK, HFK and TMP. In the case of GW the effect of pulp consistency in the model is negligible and with FPF pulp consistency has no effect on the air content measurement result.

The effect of bubble size was evaluated only qualitatively. Value 1 was determined as the predictor for small micro bubbles, and value 2 when macro bubbles were added. Bubble type was the third most important predictor in the model with SWK, TMP and fine paper furnish. With these pulp types changing bubble type from type 1 to type 2 slightly reduced the air content measurement result of the sonar method compared to the microwave method.

Most insignificant predictors in the model with all pulp types were flow velocity and pressure.



**Figure 5.** Sonar method vs. microwave method. Linear regression line is presented for micro and macro bubbles combined.

## Conclusion

Gas content measurement of pulp suspension has been a great challenge for pulp and paper industry. Few off-line methods have been presented and some are in regular use in pulp and paper mills, but accurate inline measurement has yet to be established. In these experiments novel inline method based on sonar technique was tested. Microwave and radiometric methods were used as reference measurements. Results show that the sonar method measures gas content of pulp suspensions accurately, independently of pulp type, bubble size, pressure and flow velocity. Only pulp consistency seemed to have a minor effect on the measurement result, but already the accuracy of this first industrial application is adequate for control applications.

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Appendix 1. Slope of correlations and correlation coefficients.

	<b>HW</b>	<b>SW</b>	<b>TMP</b>	<b>GW</b>	<b>FPF</b>	<b>Av.</b>
<b>MW vs. FA</b>						
<b>C-slope</b>	1.118	0.998	0.981	1.157	1.110	<b>1.072</b>
<b>C-coefficient</b>	0.902	0.847	0.759	0.779	0.785	<b>0.815</b>
<b>RM vs. FA</b>						
<b>C-slope</b>	1.410	1.271	1.274	1.222	1.238	<b>1.283</b>
<b>C-coefficient</b>	0.887	0.847	0.747	0.719	0.764	<b>0.793</b>
<b>MW vs. RM</b>						
<b>C-slope</b>	0.772	0.757	0.738	0.845	0.783	<b>0.779</b>
<b>C-coefficient</b>	0.964	0.929	0.913	0.924	0.957	<b>0.937</b>
<b>SM vs. FA</b>						
<b>C-slope</b>	0.145	0.877	0.939	0.681	1.021	<b>0.733</b>
<b>C-coefficient</b>	0.154	0.820	0.686	0.518	0.720	<b>0.580</b>
<b>SM vs. RM</b>						
<b>C-slope</b>	0.327	0.729	0.907	0.823	0.772	<b>0.712</b>
<b>C-coefficient</b>	0.378	0.945	0.831	0.875	0.847	<b>0.775</b>
<b>SM vs. MW</b>						
<b>C-slope</b>	0.856	0.946	0.907	0.922	0.948	<b>0.916</b>
<b>C-coefficient</b>	0.761	0.978	0.831	0.974	0.914	<b>0.891</b>