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# Modern Paper Quality Control

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## ABSTRACT

The increasing functional needs of top-quality printing papers and packaging paperboards, and especially the rapid developments in electronic printing processes and various computer printers during past few years, set new targets and requirements for modern paper quality. Most of these paper grades of today have relatively high filler content, are moderately or heavily calendered, and have many coating layers for the best appearance and performance.

In practice, this means that many of the traditional quality assurance methods, mostly designed to measure papers made of pure native pulp only, can not reliably (or at all) be used to analyze or rank the quality of modern papers. Hence, introduction of new measurement techniques is necessary to assure and further develop the paper quality today and in the future.

Paper formation, i.e. small scale (millimeter scale) variation of basis weight, is the most important quality parameter of papermaking due to its influence on practically all the other quality properties of paper. The ideal paper would be completely uniform so that the basis weight of each small point (area) measured would be the same. In practice, of course, this is not possible because there always exists relatively large local variations in paper. However, these small scale basis weight variations are the major reason for many other quality problems, including calender blackening, uneven coating result, uneven printing result, etc.

The traditionally used visual inspection or optical measurement of the paper does not give us a reliable understanding of the material variations in the paper because in modern paper making process the optical behavior of paper is strongly affected by using e.g. fillers, dye or coating colors. Furthermore, the opacity (optical density) of the paper is changed at different process stages like wet pressing and calendering.

The greatest advantage of using beta transmission method to measure paper formation is that it can be very reliably calibrated to measure true basis weight variation of all kinds of paper and board, independently on sample basis weight or paper grade. This gives us the possibility to measure, compare and judge papers made of different raw materials, different color, or even to measure heavily calendered, coated or printed papers.

Scientific research of paper physics has shown that the orientation of the top layer (paper surface) fibers of the sheet play the key role in paper curling and cockling, causing the typical practical problems (paper jam) with modern fax and copy machines, electronic printing, etc. On the other hand, the fiber orientation at the surface and middle layer of the sheet controls the bending stiffness of paperboard. Therefore, a reliable measurement of paper surface fiber orientation gives us a magnificent tool to investigate and predict paper curling and cockling tendency, and provides the necessary information to fine-tune the manufacturing process for

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optimum quality.

Many papers, especially heavily calendered and coated grades, do resist liquid and gas penetration very much, being beyond the measurement range of the traditional instruments or resulting inconveniently long measuring time per sample. The increased surface hardness and use of filler minerals and mechanical pulp make a reliable, non-leaking sample contact to the measurement head a challenge of its own. Paper surface coating causes, as expected, a layer which has completely different permeability characteristics compared to the other layers of the sheet.

The latest developments in sensor technologies have made it possible to reliably measure gas flow in well controlled conditions, allowing us to investigate the gas penetration of open structures, such as cigarette paper, tissue or sack paper, and in the low permeability range analyze even fully greaseproof papers, silicon papers, heavily coated papers and boards or even detect defects in barrier coatings! Even nitrogen or helium may be used as the gas, giving us completely new possibilities to rank the products or to find correlation to critical process or converting parameters.

All the modern paper machines include many on-line measuring instruments which are used to give the necessary information for automatic process control systems. Hence, the reliability of this information obtained from different sensors is vital for good optimizing and process stability. If any of these on-line sensors do not operate perfectly as planned (having even small measurement error or malfunction), the process control will set the machine to operate away from the optimum, resulting loss of profit or eventual problems in quality or runnability.

To assure optimum operation of the paper machines, a novel quality assurance policy for the on-line measurements has been developed, including control procedures utilizing traceable, accredited standards for the best reliability and performance.

## 1. Current Paper Trends

For many reasons, it is desirable to use lowest paper weight possible, without sacrificing paper end-use functionality or printing quality. As paper products often compete with other visually attractive (packaging) materials or are used as a media when building positive impressions of certain goods in advertising material, appealing appearance of paper is essential. Making functional, high-quality printed packages includes many process stages where the paperboard must allow a variety of treatments without significant negative impact in paper structure or end-product quality. There is a continuous aim to lower raw material and chemical consumption in further processing which sets even higher requirements for uniform paper quality. Recycling of raw materials, resulting from the demand of minimizing waste (obligatory by environmental laws in many countries) may limit available choices when selecting a suitable furnish for paper-making processes.

Inevitably, all converting and printing processes will be run faster. For physical reasons, 15 m/s for web speed is mentioned to be close to the possible limit in newsprint. On the other hand, the popularity of full-color printing is rapidly increasing, which is also challenging the printing equipment design. However, photographic quality printing with high color content on low basis weight papers requires a lot from paper mechanical properties, paper stability and surface quality.

Electronic printing processes and computer printing technologies, especially color ink-jet printing and color laser printing, have developed tremendously during recent years, offering very high printing resolution with very high quality.

Waterless offset printing (which is currently in prototype phase) may in the future offer a seriously considerable alternative for wet offset printing. However, water most probably will continue to play a major role in different processes for the next few years.

## 2. Paper Quality Requirements

Most important is to have as uniform paper as possible; ideally, there would be zero variation. In many cases, a good uniformity (small variation) of a certain quality parameter is more critical than the average level. As paper will undergo additional treatment and handling in varying conditions, it is necessary to maintain good stability and adequate web strength (wet and dry). Paper must be visually acceptable, having good appearance with good printability. And significant amount of raw materials used should be suitable for recycling or at least reasonably well naturally combustible.

In modern papermaking concept, often different types of fibers are used in a single product. Broke contains already all the chemical additives, changing its sheet forming characteristics. For better paper stability and strength, both resins and surface sizing is usually used. Most of the paper grades possess relatively high mineral filler content, are moderately or heavily calendered, and have many coating layers with optical brighteners for the best appearance and performance.

These raw material components are both mechanically and optically heterogeneous, each of which are being used to improve certain part of paper functionality or visual appearance. The optical behavior of paper is controlled and affected independently on local basis weight variation by various raw materials, additives and at different process stages like calendering. To improve print quality, compressed sheet structure with relatively closed surface porosity is preferred. Finally, there may be additional paper surface treatments for the final touch.

## 3. Quality Measurement Challenges

All of the paper quality measurements should be judged basing on the reliability of the selected measuring method and usefulness of the equipment. A reliable, regular instrument calibration in all cases is essential: comparison of results obtained with non-calibrated measurements is meaningless. When measuring the modern papers, especially for quality improvement or product development purposes, the instrument should be capable to reliably detect usually very small differences. This challenges measurement accuracy, detector selectivity and sensitivity, and measurement repeatability.

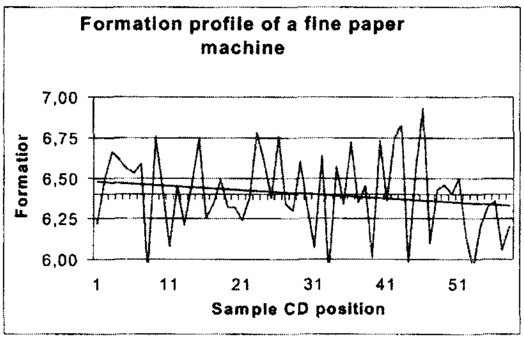
In order to be able to understand the interrelationship between selected quality measurement and paper, the measurement method should incorporate an unambiguous connection to the paper structure with good correlation to practice. In addition to this, the equipment should be able to produce a simple and practical results index, which would be easy to use and preferably universally applicable.

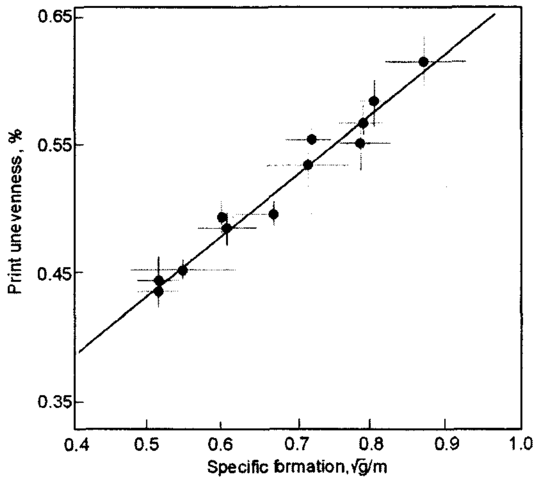
In practice, this means that many of the traditional quality assurance methods, mostly designed to measure papers made of pure native pulp only, can not reliably (or at all) be used to analyze or rank the quality of modern papers. Hence, introduction of new measurement techniques is necessary to assure and further develop the paper quality today and in the future.

## 4. Formation

Paper formation, i.e. small scale (millimeter scale) variation of basis weight in-plane, is the most important quality parameter of papermaking due to its influence on practically all the other quality properties of paper. The ideal paper would be completely uniform so that the basis weight of each small point (area) measured would be the same. In practice, of course, this is not possible because there always exists relatively large local variations in paper as well as a cross-machine formation profile. However, these small scale basis weight variations have proven to be the major reason for many other quality problems, including calender blackening, uneven coating result, uneven printing result, etc.

***An example of a formation profile:***
***Correlation between paper formation and print uneveness***[1)]

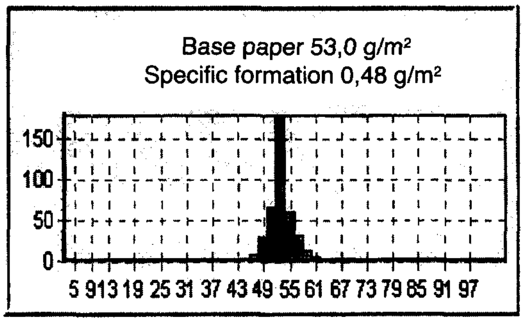


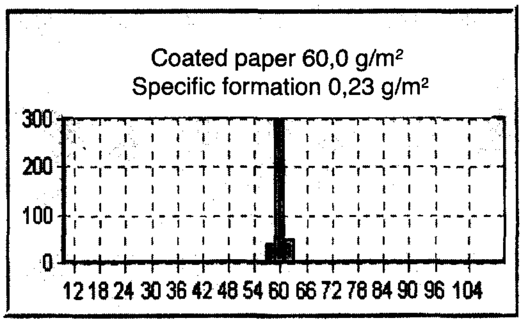




Paper formation affects directly other quality properties of paper, like

- Cockling, which is a result of structural non-uniformity and fibre orientation; occurs when (local) moisture changes
- Strength (local weak-points dominate in laboratory scale measurements)
- Optical properties (where variations in local thickness and optical density dominate)
- Calender blackening (heavy weight points most probably carry major part of the calender nip load, altering locally the optical density of the sheet)
- Uneven coating quality (big holes will be filled with coating color whereas high 'hill-top' areas may still remain without coating in blade coating process
- Print quality unevenness, resulting from
  - variations in local porosity
  - poor formation is transformed to variation in surface and absorption properties in calendering.

***Formation affects coating quality:***




It should be noticed, however, that poor formation can NOT be corrected later by any further treatment of the web or in any paper converting process.

Even today, formation is too often assessed just visually, by looking a sheet of paper against transmitted light, obtaining only a very subjective impression of paper structure (Look-through). Different kinds of optical testers are being used to obtain quantitative rankings (optical 'formation' = numerical ranking of visual inspection) that would be independent of the observer but would well correspond to the visual assessment. However, various raw-material and process factors do influence light transmittance in paper and do impair the correspondence between basis weight and the optical formation measurement (or visual assessment).

Hence, the traditionally used visual inspection or optical measurement of paper does not give us a reliable understanding of the mass variations in paper, because in modern paper making process the optical behavior of paper is strongly altered by using e.g. fillers, dye or coating colors. Furthermore, the opacity (optical density) of paper is changed at different process stages like wet pressing and calendering.

Optical formation testing methods cannot incorporate any reliable calibration routine, because all of the paper raw material components have different optical characteristics and optical properties of paper web are modified at various process stages. It may be concluded that the optical measurement is not suitable for most of the modern paper grades (with relatively high filler content, coating, calendering or that are made of heavily beaten pulp, nor does it apply for dyed or printed papers). Therefore, the formation of sophisticated paper grades of today is practically impossible to measure optically and such a measurement may lead to completely erroneous results. For this reason, visual assessment and optical evaluation should be accompanied with a measurement that gives reliable results independent on paper grade and manufacturing process.

The greatest advantage of using beta transmission method to measure paper formation is that it can be very reliably calibrated to measure true basis weight variation of all kinds of paper and board, independently on sample basis weight or paper grade. This gives us the possibility to measure, compare and judge papers made of different raw materials, different color, or even to measure heavily calendered, coated or printed papers. It is also possible to compare paper quality obtainable by different manufacturing processes (different paper machines).

***Beta formation measurement is superior:***

| | Beta | Optical |
|---|---|---|
| Accuracy | Excellent | Poor |
| Calibration | Yes | No |
| Paper grades | All | Limited |
| - calendered | Yes | No |
| - coloured | Yes | No |
| - coated | Yes | No |
| - printed | Yes | No |
| - thick sheets | Yes | Limited |
| Operation | Easy | ??? |

Practical sheet non-uniformity measurement suggestions:

- Paper formation (= small scale basis weight variation) should be measured by using beta method.
- Paper appearance (= visible structural texture of paper) can be measured by using optical method (which also correlates well with visual inspection)

## 5. Orientation

In mill-made papers, typically most of the fibers are lined to about machine direction. This can easily be visualized by adding some dyed fibers into the stock flow.

*Average fibre orientation* through the sheet affects directly in-plane mechanical properties and in-plane dimensional stability of paper. Commonly used measurements are based on either studying MD/CD tensile test ratio, detecting changes in light spot shape on the opposite side of the sheet, or measuring in-plane ultrasonic sound speed in media.

*Surface fibre orientation* means, that only the fibers located at top or bottom surface of the paper are being analyzed. Scientific research of paper physics has shown that the orientation of the surface layer fibers of the sheet play the key role in paper curling and cockling, causing the typical practical problems (paper jam) with modern fax and copy machines, electronic printing, etc. In practice, if there exists adequate fibre orientation difference between the sheet surfaces, the paper most probably will curl (or twist) when moisture changes.

On the other hand, the fiber orientation at the surface in comparison to the middle layer of the sheet controls the bending stiffness of paper. In addition to this, the variation of the fibre orientation through the thickness of the sheet is also relevant to the *performance* of the sheet.

From the quality paper production point of view, controlling the surface fibre orientation profiles across the machine is not easy at all, but it is most essential for papermills producing sheeted qualities for computer printing or copying purposes.

Therefore, a reliable measurement of paper surface fiber orientation gives us a magnificent tool to investigate and predict paper curling and cockling tendency, and provides the necessary information to fine-tune the manufacturing process for optimum quality.

## 6. Gas Penetration

Gas and fluid transport characteristics of paper as well as paper porosity are commonly studied by measuring air permeability through the sheet. Many papers, especially heavily calendered and coated grades, do resist liquid and gas penetration very much, being beyond the measurement range of the traditional instruments or resulting inconveniently long measuring time per sample. The increased surface hardness and use of filler minerals and mechanical pulp make a reliable, non-leaking sample contact to the measurement head a challenge of its own. Paper surface coating causes, as expected, a layer which has completely different permeability characteristics compared to the other layers of the sheet.

It can be shown that the steady state **volume flow** $Q$ of a gas through a material can be obtained by the equation of d'Arcy, which can be approximated by a formula

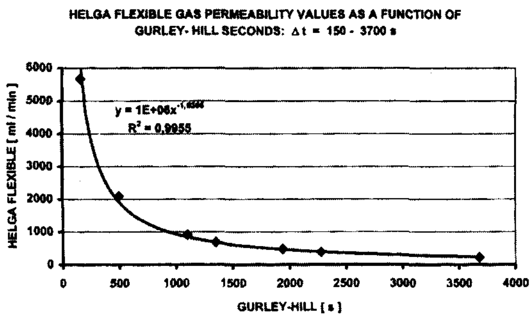
$$Q \propto \frac{K}{l}$$

**Volume flow** $Q$ of a gas is proportional to the **permeability constant** $K$ of the material and inversely proportional to the **thickness** $l$ of the material.

The latest developments in sensor technologies have made it possible to reliably measure gas flow in well controlled conditions, thus allowing us to investigate the gas penetration of almost all kinds of sheet structures: high permeability, relatively open porosity sheets, such as cigarette paper, tissue, filter or sack papers; and in the low permeability range it is possible to analyze greaseproof or fully greaseproof papers, release papers, board, heavily coated papers and paperboards or even detect defects in barrier coatings! Even nitrogen or helium may be used as the gas, giving us completely new possibilities to rank the products or to find correlation to critical process or converting parameters.

The novel Ambertec *Gas Penetration Tester HELGA*® is based on calibrated gas flow measurement within range 10 micro liters per minute upto 20 000 ml/min where, depending on the application, air, nitrogen or helium may be used as a gas. Most of the paper and paperboards can be measured within 15.60 seconds, in comparison to the traditional methods which may take several hours per sample.

As always, introducing more accurate and selective measuring techniques gives us a




chance to compare and rank different products the way that has not been possible before, and to find new correlations to porosity and penetration resistance. Studying and comparing gas penetration, when measuring from top and bottom sides of the sheet, clearly not only shows the two-sidedness of paper but also helps us to understand the impact of compressed paper structure or surface coating to printing ink penetration, which does determine print quality and printability.

An excellent correspondence has been found to exist between paper greaseproof properties and gas penetration, the information readily to be used for production control of these grades. Similarly, in the case of release papers, the new gas penetration information has successfully been used in controlling the silicon application process. There also exists very good correlation to printability of coated papers.

In one study, experimentally determined volume flow values of $N_2$ gas have an almost constant value when plotted as a function of the paper basis weight of the coated paper. However, the permeability constant $K$ of the material increases a lot due to dependence of the gas flow with the thickness of the material. We would like to emphasise that printing is a forced process where the permeability constant $K$ of the material is one of the crucial parameters.

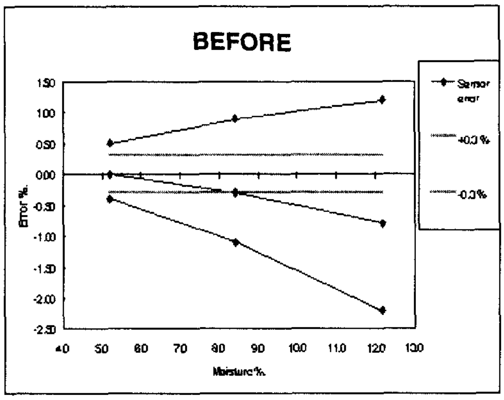
Therefore a gas permeability measurement by which one can determine the volume flow of a gas as accurately as possible provides means to estimate the permeability constant K of the material and therefore also the printing quality.

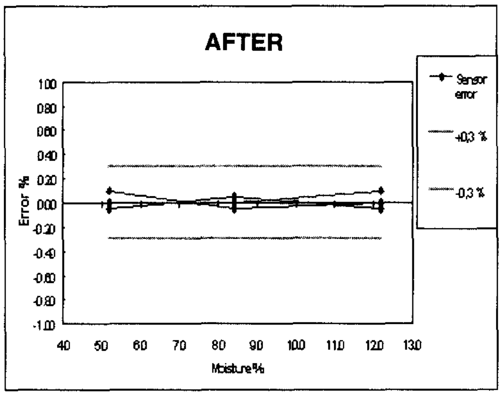
## 7. On-Line Quality Measurements

All the modern paper machines include many on-line measuring instruments which are used to give the necessary trend information for automatic process control systems. Hence, the reliability of this information obtained from different sensors is vital for successful process optimization and good process stability. If any of these on-line sensors do not operate perfectly as planned (having even very small measurement error or instrument malfunction), the process control will set the machine to operate away from the targeted optimum, resulting loss of profit or eventual problems in quality or runnability.

The different on-line measurements should be, as well as possible, compensated against harsh process conditions, sensor aging and equipment wear-out. The measurement accuracy and reliability should not be affected by varying web basis weights or paper grades (different raw material compositions used) on the same paper machine. This can be obtained by systematic calibration and performance follow-up of the on-line sensors. In order to assure optimum operation of the paper machines, a novel quality assurance policy for the on-line measurements has been developed, including control procedures utilizing traceable, accredited standards for the best reliability and performance.

***A case example of 'identical' moisture sensors:***




## 8. A Brief Summary

Reliable paper quality measurements, both laboratory and on-line, are the essential key to successful quality assurance, resulting better production performance and higher profits.

## Literature Cited

1. K. Niskanen, I. Kajanto and P. Pakarinen, "Paper structure", Papermaking science and technology, Finnish Paper Engineer's Association and TAPPI, 1998, Book 16, p. 36.