# The Practical Measurement of Paper Condition. (Why bother with Quality Control when the paper is wavy)

PETER GREAVES MIOP

## Introduction

The Subtitle of this paper 'Why bother with Quality Control when the paper is Wavy?' is not an idle thought, nor an attempt to be dramatic for the sake of it. Many of the papers presented at this Conference are concerned with Printing Quality Control in the broadest sense. Add to the Printing Control cost, the enormous amount of testing which is applied during the production of Paper. All the results of control and testing rest on one major requirement - that the paper proceeds satisfactorily through the press, does not crease and faithfully reproduces all colours in register.

It is, unfortunately, not a rare situation to reach a make-ready completion, load up and start the press only to find that the paper exhibits creasing or misregister either progressively or at the back-edges. A more costly disaster for sheetfed printing occurs when the first side printing cannot be backed up, this being due to the distortion of the paper either between workings or as a consequence of the first working.

There have been considerable advances in recent years in improving understanding of the mechanism which controls paper shape. Measurement systems have greatly advanced and progressed towards the measurement of Equilibrium Relative Humidity and Temperature, which is taking the place of Moisture Content as a Printing performance specification. The meaning and relevance of ERH will be discussed more fully as will systems for measurement of sheets, stacks and moving webs.

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One critisism of the past concerning Relative Humidity related measurements has been the confusion which has existed over Standards. The new UK National Standard was launched in a Conference in New York - Moisture and Humidity 1985, 15-18th April. This Standard will join the standard at NBS and will provide much greater certainty and traceability for RH and RH related measurements. The principle and operation of this new Standard will be discussed.

## Why does Paper Distort?

The production of wavy edges or tight edges on stacks of paper, slack or tight edges on reels is almost always due to an inbalance or lack of balance between the paper and its environment at some stage in its life. The inbalance occurs where, for instance, cold paper is unwrapped in a warm warehouse or printing room or a difference exists between the Relative Humidity of the air and the Equilibrium Relative Humidity of the paper. To take the first situation, paper has perhaps travelled for some time in a cold lorry and the edges of this paper have become measurably cold, the paper has not been allowed to come into equilibrium with the condition of the works and has been unwrapped and prepared for printing or processing. The moisture shock which occurs at the stage of unwrapping is sufficient to create wavy edges on the paper. This can be demonstrated by the Dew Point shock which occurs when someone wearing spectacles goes into a room which is very much warmer than the environment he has just left - the spectacles steam up. In the case of paper this condensation effect is invisible, but the result is no less dramatic. Moisture vapour does condense on cold paper stack or reel edges and a wave will be produced within minutes.

The inbalance of Ambient Air RH and Paper ERH is perhaps a less recognised cause of a wide number of problems; for instance distortion, creasing, wavy edges, curl, reduction in fold strength, reduction in tensile strength, rigidity, problems with carbonising, cutting and creasing, and general web and sheet running problems on printing machines. The point of the title is really to underline the fact that there are sophisticated testing procedures for such properties as smoothness, absorption, porosity, pick or ink mileage, dot gain and ink density etc, but in the final event when the paper arrives at the press, or even worse, at one of its last stages of production, when it has become very expensive, the paper has been modified in its condition to such a point that it will not proceed through the press nip in a flat condition. Having looked at these conditions in general terms it is necessary to be more specific and to say that the properties which have been discussed so far are entirely measurable and in a large number of cases, the problems are preventable.

## Temperature

Firstly, we should look at temperature since the measurement of temperature has been related to traceable standards for a number of years. Temperature measurements can be made in air prior to unwrapping or taking any wrappers from the stacks of paper or reels and similar measurements can be made in the paper itself using temperature probes. Providing a balance of condition has been achieved between the paper and the environment into which it has been placed it will then be generally safe to unwrap the paper from the aspect of temperature.

Referring to the example of misting spectacles, there is no doubt that a significant temperature difference between a stack of paper or reels and the new environment into which it is placed will cause edge distortion. The distortion, once developed, is normally irreversable. Paper should not be unwrapped and left unprotected to allow it to 'breathe' or 'condition'. This misguided practice must have ruined many tonnes of otherwise satisfactory paper. This last statement may appear to be obvious, but our experience shows that the 'open to condition' belief still holds in many Printing Houses from the large to the very small.

Paper achieves temperature equilibrium at a much faster rate than it reaches humidity equilibrium, but the time required to correct a 10 degree Celsius difference must be considered in terms of days rather than hours, since paper is an exceptionally good insulator and therefore resists temperature change.

## Relative Humidity and Equilibrium Relative Humidity

Next we should look at Relative Humidity and Equilibrium Relative Humidity since this is more likely to be the cause of distortion. Temperature can be sensed fairly well by the body or hand, RH and ERH cannot be so judged and since the body perspires, totally inaccurate information can be perceived about the condition of air or material. There is no alternative but to measure. While ERH is being measured, temperature will be displayed from the sensor of the instruments which will be covered later in more detail.

The ERH of paper is a ratio of the partial moisture vapour pressure generated by paper in a closed system (stack) or from th barrier layer of air moving in dynamic equilibrium with a web. Relative Humidity is a ratio of actual vapour pressure to the saturation vapour pressure at the same temperature. Both these values are expressed as a percentage and are subject to the same physical equation:-

Percentage RH is equal to

$$\frac{\text{Moisture Vapour Pressure}}{\text{Saturation Moisture Vapour Pressure}} \quad \text{MULTIPLIED BY 100}$$

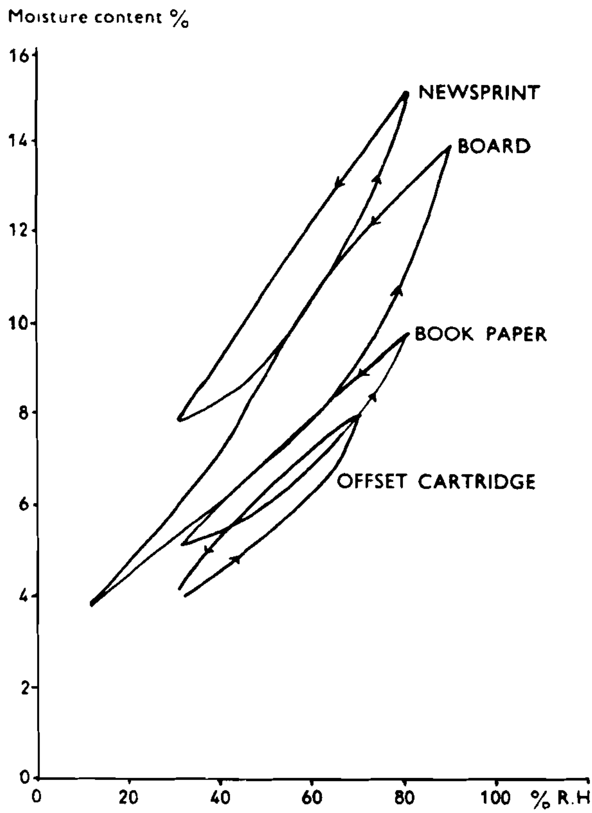
At the same temperature

Wide fluctuations normally occur in the RH of air between, say, Winter and Summer or between differing geographical locations, these differences are further influenced by artificial heating. Consider these fluctuations and their likely effect upon the major component of paper as recorded by - James P. Casey "Cellulose has a very strong affinity for water. In fact, absolutely dry cellulose is one of the most hygroscopic substances known and it will take up moisture from nearly all known drying agents, including phosphorous pentoxide.

Paper will absorb or desorb water vapour until its condition is in equilibrium with the surrounding atmospheric environment. Unfortunately the major changes will occur very slowly." (1)

Another vital factor in considering the distortion of paper is hysteresis. Hysteresis effects account for the permanency of distortion since the cellulose fibres making up paper do not recover to their original dimension, but in their partial recovery a different route of expansion and contraction is taken. (2) Cellulosic paper fibres expand and contract differentially between their length and circumference. Page found the values to be in order of 1-2 percent in length and 30 percent in diameter on drying from near saturation. (3)

The second hysteresis influence on paper concerns the effect on moisture content by conditioning paper from a high or low relative humidity. If a stack of paper approaches equilibrium with a given atmospheric RH from a higher ERH, then the final moisture content will be higher. In the reverse condition, a lower final moisture content will result from lifting the ERH to equal that of a higher RH. This hysteresis effect has a marked influence on the moisture content, but not on ERH, since by definition, an equilibrium condition is reached when the ERH condition of the stack of paper agrees with the RH of the surrounding air.




**Typical Hysteresis Curves (PIRA)**

Whether wavy or tight, due to absorption or desorption and, taking into account the hysteresis effects, the net result of this difference is more often than not a distortion which prevents otherwise satisfactory paper from being printed.

## Equilibrium Relative Humidity

The term ERH, Equilibrium Relative Humidity, has been regularly used over the past twenty years to denote the RH condition of a material. Some European Countries use the term REM standing for Relative Equilibrium Moisture, but since the values obtained from measurement are based on a 0-100 percent scale and equivilent to percent RH, ERH bears a stronger relationship to the true meaning of the term.

Equilibrium Relative Humidity of paper is based on the measured values obtained from paper and air ranged on a 0-100 percent scale. The same instrument can normally be employed to obtain both values in a short time thus avoiding the risk of instrument to instrument variation where two instruments of differing types are used.

It is accepted that paper absorbs water from the atmosphere and gives up water to the atmosphere until it reaches equilibrium. This exchange of water vapour depends on several factors, but most influence is through ERH. If the atmospheric RH condition is above the ERH of the paper, water vapour will be absorbed from the atmosphere into the material. If the RH of the atmosphere is below the ERH of paper, water vapour will be given up to the atmosphere. Since these exchanges normally occur at the edges of reels and stacks the result is slack or wavy edges or, conversely, tight edges.

ERH exerts a partial vapour pressure within a barrier layer of a moving web and between sheets in a stack. The partial vapour pressure can be conveniently measured and displayed or recorded with electronic ERH sensing instrumentation. The ERH value together with the stack or web temperature, measured concurrently with the same instrument, give the major amount of information required on paper condition and its relationship with the surrounding atmosphere or projected atmosphere.

The sensitivity of this type of equipment will permit differential measurements to be made at the edge to centre of a given stack of paper or web and provide information which can be used to produce a profile. A profile of paper can yield some very interesting information. The normal measurement time for single position measurement is in the region of one to two minutes and for moving webs is in the order of less than one second.

The characteristic condition of a stack of paper having an ERH of, say, 50 percent when exposed to a continuous condition of 30 percent RH will be tight edges with sprung corners. Many measurements carried out on such stacks have revealed that whilst the edges have, as expected, assumed the condition of 30 percent ERH, the centre remains at 50 percent and a band exists within the stack which measures above 50 percent ERH. In some cases the band, occurring 7-10 centimetres in from the edge, will measure up to 5 percent ERH above the main condition. This condition could account for the springing which is often exhibited on tight edged paper.

Whereas, it can be imagined that moisture is taken from the paper by the lower ambient condition, this effect would suggest a mobility of the moisture vapour in two directions. It is suggested that this can only be measured accurately with the modern electronic instruments operating from a small sized sensor which takes its measurement sample at a finite position of only 1.5 square centimetres of the paper surface area.

## Moisture Content and ERH

### Moisture Content

The traditional system of determination of moisture content as laid down in BS 3433 involves the collection of at least 50 grammes of sample to be placed in air-tight containers, paying attention to prevent changes occuring to the sample of air, and weighing. Following the initial weighing in sealed containers the sample is placed in a ventilated oven maintained at a temperature between 103 degrees Celsius and 105 degrees Celsius for a period of time which can be up to two hours. The container lids, for replicate samples, which were removed in the oven are replaced and the samples are cooled and reweighed. Re-drying and weighing continues until a constant weight is achieved where the difference between successive weighings is not greater than 0.1 percent of the original moist weight. From the weight difference is calculated the total moisture content. (4)

Problems arise with this test mainly in the collection of sample and the fact that all volatile substances are driven off and calculated as moisture. It is not unusual to witness the unprotected moisture content sample being ceremoniously transported to the Laboratory which may be some distance from the Printing or Paper Making Machine. The moisture content will have changed, but it is still recorded without question and, that is the moisture content for a large quantity of paper.

Another frequent cause of large variation results from transporting samples in polythene bags. Although often water resistant, thin polythene tends to be moisture vapour permeable and samples can be re-conditioned by the environment.

The total weight difference is taken as the moisture content, which might include a percentage of volatile component and certainly includes bound and unbound moisture. In the case of coated papers up to 2 percent of the total moisture can be bound in the form of water of crystallization. A 6 percent moisture content coated paper has been seen to become very wavy in an atmosphere of 55 percent RH, 21 degrees Celsius. The ERH of this confirmed sample of paper was found to be 38 percent and therefore significantly below the ambient RH.

## ERH Measurement

ERH is measured by inserting a sword containing an electro-chemical sensor into a stack of paper and reading the results of ERH and temperature condition after a suitable time of equilibrium, speed of equilibrium depends largely upon the original temperature difference between the sword and the paper.

Laboratory tests on single sheets can be made with an instrument which acts as a heat sink for sample temperature difference and the sensor transmits ERH to be displayed or recorded within seconds.

Continuous measurements are made on webs of paper travelling at speeds up to 800 metres per minute under practical conditions with the Hygrojet. This system is successfully operated at this speed to control paper machines and conditioners. The Hygrojet also controls the moisture condition of photographic paper and film. In this instance ERH is determined from the barrier layer of air drawn from the surface of the moving web. The Hygrojet has proved in practice to be very accurate with fast response to changes in ERH and Temperature.

Perhaps it would be appropriate at this stage to explore why, although there is a broad relationship between ERH and moisture content important differences do exist. The differences are considered to be due to the variable ratio of bound and unbound moisture measured in total moisture content determination, but differentiated by ERH measurement. It is necessary to examine the theory of water and water vapour retention in paper. There are two main classifications of moisture contained in materials bound and unbound. The relative proportion of bound and unbound moisture in paper is conditioned by temperature and if the temperature surrounding the paper is increased, the temperature of the paper increases, bound moisture is converted to unbound moisture and driven off into the air until the paper dries out in the extreme condition.

The converse effect of reducing temperature converts unbound to bound moisture, which reduces the water activity (4) to a point where a product may be refrigerated or chilled to reduce decay due to microbiological attack. It is suggested that bound moisture has little influence on varying many paper properties, whilst knowledge of unbound moisture is currently being applied in a number of other industries and in different parts of the World to numerate the state of contained moisture in materials which influences product condition or stability to microbial attack and decay. This work is based entirely on ERH technology and not on the total moisture condition of the materials.

In the cellulose component of paper, as made for delivery correct for printing or converting, there are contained the two types of moisture:

Colloidal Water and Capillary Water. Collodial or bound water is held firmly by adsorption onto the fibre and requires considerably more energy to change in its state than that produced by ambient RH condition. Capillary or unbound water is readily responsive to humidity changes and has a major influence on fibre dimension. The condition and ratio of bound and unbound moisture is further aggravated by loadings and coatings which each have equilibrium conditions of bound and unbound water.

ERH measurements do not always relate to gravimetric moisture content since oven dry and other total moisture content systems account for most of the bound and unbound moisture in the total result. ERH is a value obtained for unbound moisture and therefore relates most closely to the performance specification required for paper in its finished condition.

To sum up, the two vital measurements to be made on paper are temperature and ERH. These two values can be compared directly without calculation and related to ambient conditions, or even the projected conditions prevailing where the paper is to be unwrapped. All this information can be gained from simple measurement. Total moisture content is, on the other hand, an essential measurement for Paper Mills since it is both a value to control manufacture and a final economic measure in paper making. Moisture content is of little value to Printers or Convertors since it cannot be directly related to paper condition nor to what will happen to paper when it is exposed to known RH conditions, there are therefore two values for two different criteria.

Many Paper Mills now make to ERH specifications and mark the condition on the outside wrappers. Naturally, since paper can be made and delivered to an ERH target, it is necessary for the printing or converting house to control its own conditions to within reasonable limits. In Europe the usually agreed conditions are 50 percent RH, plus or minus 2.5 percent; which is the condition most commonly achieved within a works and therefore requires least energy to maintain. This target value has reduced from 65 percent in recent years since most working environments are maintained at a higher temperature and the lower value also represents a more commonly delivered paper condition.

## Standards

Any system of measurement can only be as good as its ability to be checked and calibrated to Standards. The current standards used to calibrate Novasina Instrumentation for ERH measurement are saturated salts, presented to the sensor in a form agreeing to the guidelines of N.B.S. for humidity generation.

Saturated salts, or rather salt slurries, offer a convenient range of fixed values at known temperatures between 11 percent and 98 percent RH and, can be supplied either as a tablet which is clamped against the sensor or a 'glove' which is so arranged to contain the sensor in a sealed environment.

Salts are each supplied with tables which give the variation in generation of RH for different temperatures and therefore, a direct reading can be made for calibration purposes using a simple calculation for the salt checks, since some exhibit changes of value for temperatures other than the commonly quoted 20 degress Celsius.

It is essential that the temperature is in total agreement between the sensor, the salt and the ambient condition. If a temperature difference exists there will almost certainly be an artificial humidity created, which will be detected by the sensor. Although the sensors are temperature compensated, humidity is temperature related and therefore the calibration condition will be incorrect.

A table of values for salts was produced originally in 1919 by Robinson & Stokes (6). Since that time a number of tables have appeared and it therefore can be said that one of the criticisms surrounding salt standards is the tabulated disagreement which exists as a result of various attempts to decide an accepted value. We must be clear, pure salt slurry has a reasonably fixed value, but the tables could make it appear that wide variations can exist. To illustrate this point a table giving the differences for the most commonly used salts for humidity generation will be found in the appendix.

The most currently accepted values are those published by The National Bureau of Standards under Humidity Fixed Points of Binary Saturated Aqueous Solutions 1976 - Louis Greenspan (7).

## U.K. National Standard

Four years ago work was started to produce a UK National Humidity Standard to be provided by the National Physical Laboratory. A representative user Committee was set up and my Company has been associated with this Committee since its inception.

The project started as a direct response to the needs of UK Industry as surveyed in 1980. The problems of deviation in reported values and lack of a National traceable Standard for Defence and Aerospace work made the production of the National Standard both urgent and necessary. During the 1970's the increased use of computer based process control systems and the requirement for humidity measuring equipment with data logging for use in unmanned weather stations high-lighted the need for traceability. A single independent National Standard to which all calibrations could be traced and which in turn would be traceable to the base units of the SI system was becoming a pressing matter.

At the Conference - Moisture and Humidity 1985, in Washington on 15th-19th April 1985, the launch of the UK National Standard was made to the United States by Dr. K.F. Poulter and Dr. J.L. Hales both of N.P.L.

Close co-operation has existed between the N.P.L. and N.B.S., and the development of the UK Standard has been produced after demand from the U.K. to provide National traceability, as offered by the valuable standard for humidity held by N.B.S.

## Description of Facility

The UK facility consists of a two temperature recirculating generator covering the range of Relative Humidity from 1.0 percent to 98 percent RH, with an accuracy of plus or minus 0.5 percent RH. The ambient temperature range in the test chamber was required to be minus 30 degrees Celsius to 100 degress Celsius, controlled and measured to plus or minus 0.05 degrees Celsius. After only a short period of operation it has become clear that a greater precision has been achieved and the temperature range expanded to minus 75 degrees Celsius.

The Generator into which probes and sensors are fitted for evaluation and test is itself checked against a primary gravimetric hygrometer, which completes the system and guarantees the accuracy of the humidity and temperature of the air generated.

A broad description of the two temperature system is as follows:- Air (or other gas) traverses a saturator containing water or ice at a controlled measured temperature (the lowest temperature in the circuit) and, then proceeds past the equipment under test at a higher temperature. The temperature of the air at the point of saturation is measured using platinum resistence thermometers traceable to NPL temperature Standards. Each saturator is associated with three thermometers, one at the entry, one at the exit (the difinitive position) and one in the bath fluid.

A photograph of the generator is included at the end of this paper, together with operation diagrams. (8)

Instruments

The basic sensor and, to a large extent supporting instrumentation, which is most fully known to us is that manufactured by Novasina in Zurich. This equipment range has formed the basis for the practical measurement of ERH and has been quoted in a number of papers on this subject.

Sina was formed in 1958 by a Mill Chemist in order to make a range of instrumentation employing a unique sensor system. The basis of the sensor has changed very little, but naturally, the design and application of the instruments has developed out of all recognition.

The following is a description of the main classification of instruments for ERH and Temperature measurement.

HYGROJET (Illustration appendix 1)

The Hygrojet is an on-machine quality control measurement tool and it can be applied to the paper manufacturing machine, to laminators who adhesive laminate dissimilar materials, or at any stage where the paper is contained in a web. Since paper changes very rapidly in sympathy with its environment the most realistic measurement that can be made to paper and board are those which are closest to the end use or next stage of manufacture or converting.

The principle of the Hygrojet is to draw the attached barrier layer of air from the surface of the moving web. This barrier is sucked from the paper surface and drawn over a sensor in a chamber which has equal temperature with the sensed surface of the web. The temperature equilibrium is achieved by use of an automatically operating peltier element. An output from the sensor is displayed for both web temperature and ERH using either LED or LCD figures. The signal can also be recorded in direct linear values from 0-100 percent RH, minus 20 plus 80 degrees Celsius and outputs provided for control purposes.

The Hygrojet will operate successfully up to web speeds of 800 metres per minute. Under more practical conditions of between 6-800 metres per minute the Hygrojet exhibits an extremely high accuracy of better than plus or minus 2 percent ERH, which is roughly equivalent to plus or minus 1/4 percent moisture content. One important point in the measurement of ERH is that accuracy is independent of furnish, coating, loading content, density and within reason calliper since ERH is a measurement of the free moisture contained in paper is not conditional upon some electronic characteristic. The use of the Hygrojet in certain paper mills has proved a considerable saving in the production of paper which is not now rejected due to runability problems and can be targeted to achieve the conditions of the printing and converting processes which follow.

Sword Probe Systems (Illustration appendix 2)

It is necessary to probe stacks of paper with a rigid sword, but to sense RH and Temperature in a small local position. The sword probe type enSS, together with the portable meter Humidat IC2 offers an extremely flexible system being battery rechargeable or mains driven. ERH and Temperature are displayed and a useable output is available. Since it is necessary to achieve full equilibrium before readings of high accuracy are taken, the IC2 has a system of warning lights giving the accuracy band for each reading against time. The great advantage with this stability indication is found in routine measurement, when the operator will only take a reading when the lights are on, which is therefore when total equilibrium has been achieved.

Portable Sword Probe (Illustration appendix 3)

The demand for a 'brief case' system provided the developement of the MIK 2000 enSS. This is a battery driven hand-held device which is extremely portable and has a much shorter sword for Quality Control or Technical Service visit measurement of ERH and Temperature. Again, the system is fully checkable on-site, should the necessity arise for an accuracy confirmation.

Single Sheet Tester (Illustration appendix 4)

I do not think that the full potential of this aspect of measurement has been fully realised. The single sheet sensor acts as a heat sink to agree a sample of paper to the temperature of the test environment. This sensor measures ERH independent of temperature and offers a very fast laboratory test facility.

Air Measurement

Considering the complexities of material measurement, air measurement using the same basic technology can be achieved in a less complicated manner.

MIK 3000 (Illustration appendix 5)

Air measurement sensors, which can be checked or if necessary calibrated with the standard Sensorchecks, are widely used for displaying, recording, logging or computer control of RH and Temperature. In the UK these air measurement systems have type approval from the Government Department of the Environment, Property Services Agency.

The hand-held precision air measurement unit MIK 3000 has at this time been introduced and in this one instrument an air measurement will produce an LCD indication of temperature in degrees Celsius or Fahrenheit, RH and Dew Point.

Remote air sensors can be linked to linear transmitters which produce useable outputs in mA or mV proportional to RH and Temperature. By connecting a Humidat PA unit to either linear or non-linear transmitter output, the full benefits of a self-contained computer are employed.

The Humidat PA will accept 32 inputs of 0-20mA or 0-5V and produce a linearised evaluated output in serial interface, RS-232C/V24, with internally computed averaging and limit alarms. The Humidat PA-2 produces all the mentioned functions plus 16 additional analogue outputs of 0-20 or 4-20mA.

Although the Humidat PA has been covered under the heading of air measurement, the microcomputer will also accept and compute data from all the material measurement instruments and this has produced some fairly advanced systems with Hygrojet and even Sword probes for data collection and storage.

## Conclusions

The living, dynamic moisture condition of paper and board is Equilibrium Relative Humidity and this condition has been shown to have a direct relationship with conditions of RH in manufacture, conversion and storage.

ERH can be measured conveniently and quickly in conjunction with temperature to establish, at least, decision making measurements on delivered material to problem solving and prevention, right through to the end process. Original manufacture control and specification enables the Mill of origin and the intermediate customer, normally the Printer, to be speaking the same specification - ERH.

It can be argued that moisture content is of very little relevance to the Printer or Converter, since it cannot be directly related to his practical conditions of RH and Temperature. Also, it is now known that the bound moisture which is normally measured by gravimetric systems can account for a significant percentage of moisture, which apparently has little influence upon performance characteristics of paper and board.

At the manufacturing stage it is necessary to measure both properties of ERH and moisture content since the Paper Maker needs to know percentage moisture content for economic and other considerations. As paper is processed towards the Printer or Converter moisture content becomes less important and ERH is a specification necessity.

The measurement of ERH is simple and rapid and furthermore can be checked at any time against independent standards and therefore is an ideal measurement value for selling, buying, using and specifyig paper and board. This view of ERH can be taken as only a moment in a fast moving technology which is currently saving large sums of money through improved communication and prevention of waste.

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## References

1. James P. Casey. Pulp and Paper Chemistry and Chemical Technology Vol. 1.

2. PIRA Paper Handling and Air Conditioning Evelyn J. Pritchard.

3. D. Page The Formation and Structure of Paper Technical Section of the British Paper and Board Makers Association.

4. British Standard 3433: British Standards Institution. British Standards House, 2 Park Street, London W1.

5. Moisture Sorption Practical Aspects of Isotherm Measurement and use T.P. Labuza.

6. Robinson R.A. and Stokes R.H. Electrolyte Solutions Butterworths London 1959.

7. Fixed Points of Binary Saturated Aqueous solutions - NBS - Louis Greenspan, Humidity Fixed Points of Binary Saturated Solutions Journal of Research of the National Bureau of standards. Vol.81A,No.1, JAN.-FEBR. 1977.

8. Hales J.H. Two Temperature Generator in the UK Humidity Standard. Moisture and Humidity 1985.

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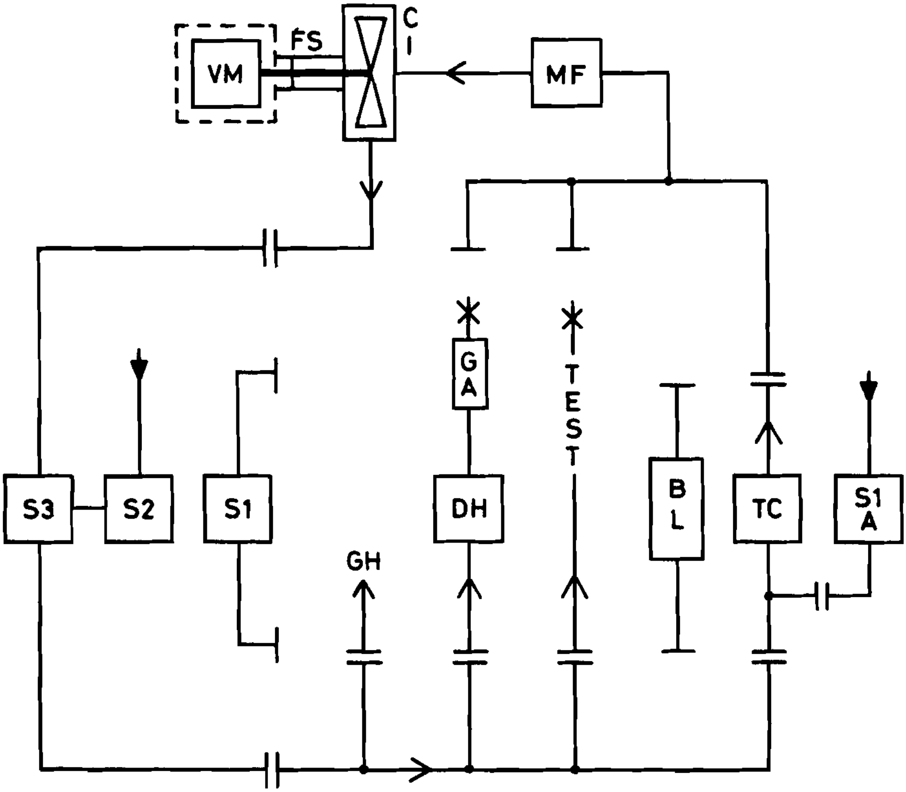
## APPENDIX

### Saturated Salt Values

| NOVASINA SALTS | | 20C | 25C | 30C |
|---|---|---|---|---|
| SAL 11 | Lithium Chloride | 11.30% | 11.30% | 11.30% |
| SAL 33 | Magnesium Chloride | 33.10% | 32.80% | 32.40% |
| SAL 53 | Magnesium Nitrate | 54.40% | 52.90% | 51.40% |
| SAL 75 | Sodium Chloride | 75.50% | 75.30% | 75.10% |
| INTERNATIONAL CRITICAL TABLES | | | | |
| | Lithium Chloride | 12.40% | 12.00% | 11.80% |
| | Magnesium Chloride | 33.60% | 33.20% | 32.80% |
| | Magnesium Nitrate | 54.90% | 53.40% | 52.00% |
| | Sodium Chloride | 75.50% | 75.80% | 75.60% |
| GREENSPAN NBS OCTOBER 1976 | | | | |
| | Lithium Chloride | 11.31% | 11.30% | 11.28% |
| | Magnesium Chloride | 33.07% | 32.78% | 32.44% |
| | Magnesium Nitrate | 54.38% | 52.89% | 51.40% |
| | Sodium Chloride | 75.47% | 75.29% | 75.09% |
| ISO APRIL 1966 | | | | |
| | Lithium Chloride | 12.00% | 12.00% | 12.00% |
| | Magnesium Chloride | 33.00% | 33.00% | 33.00% |
| | Magnesium Nitrate | 55.00% | 53.00% | 52.00% |
| | Sodium Chloride | 76.00% | 75.00% | 75.00% |


Figure 1. National Standard Generator NPL




BL Metal block for solid-state hygrometers

CI Centrifugal impeller

DH Dewpoint head

FS Ferrofluidics rotary seal

GA Gapmeter

GH Gravimetric hygrometer

⊣⊢ Cajon demountable joints

MF Mass flowmeter

S Saturator

TC Test chamber

VM Variable speed motor in pressure-tight enclosure

✱ Valve to atmosphere

▼ From pressure controller

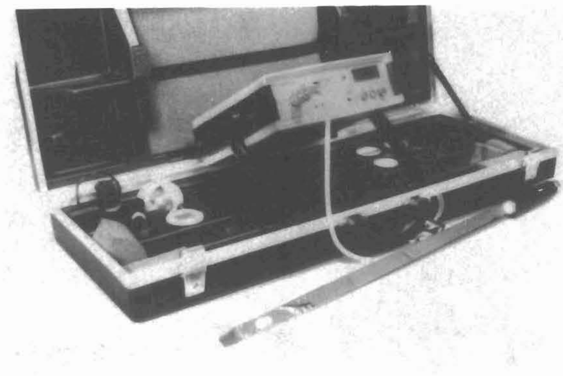


Figure 2. Sword Probe System

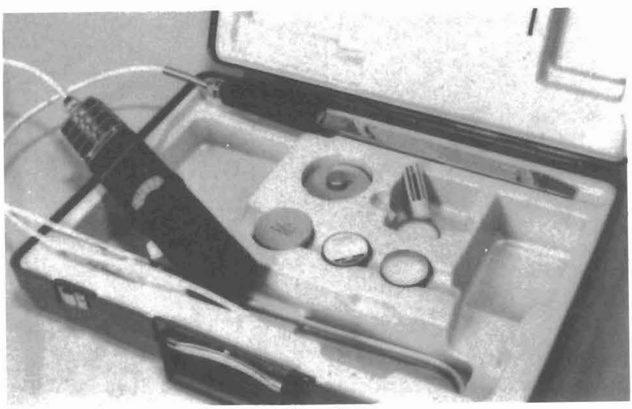


Figure 3. Portable Sword Thermohygrometer

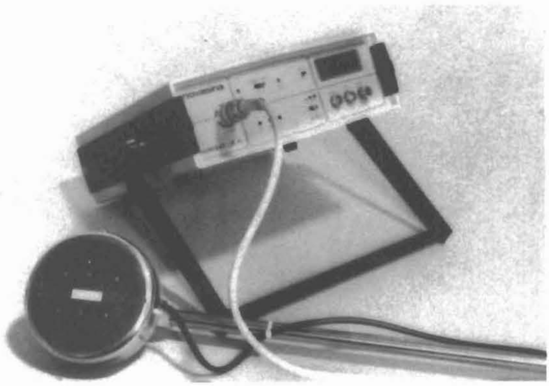


Figure 4. Single Sheet Tester

Figure 5. MIK 3000 & MIK 2000
Portable Hygrometers