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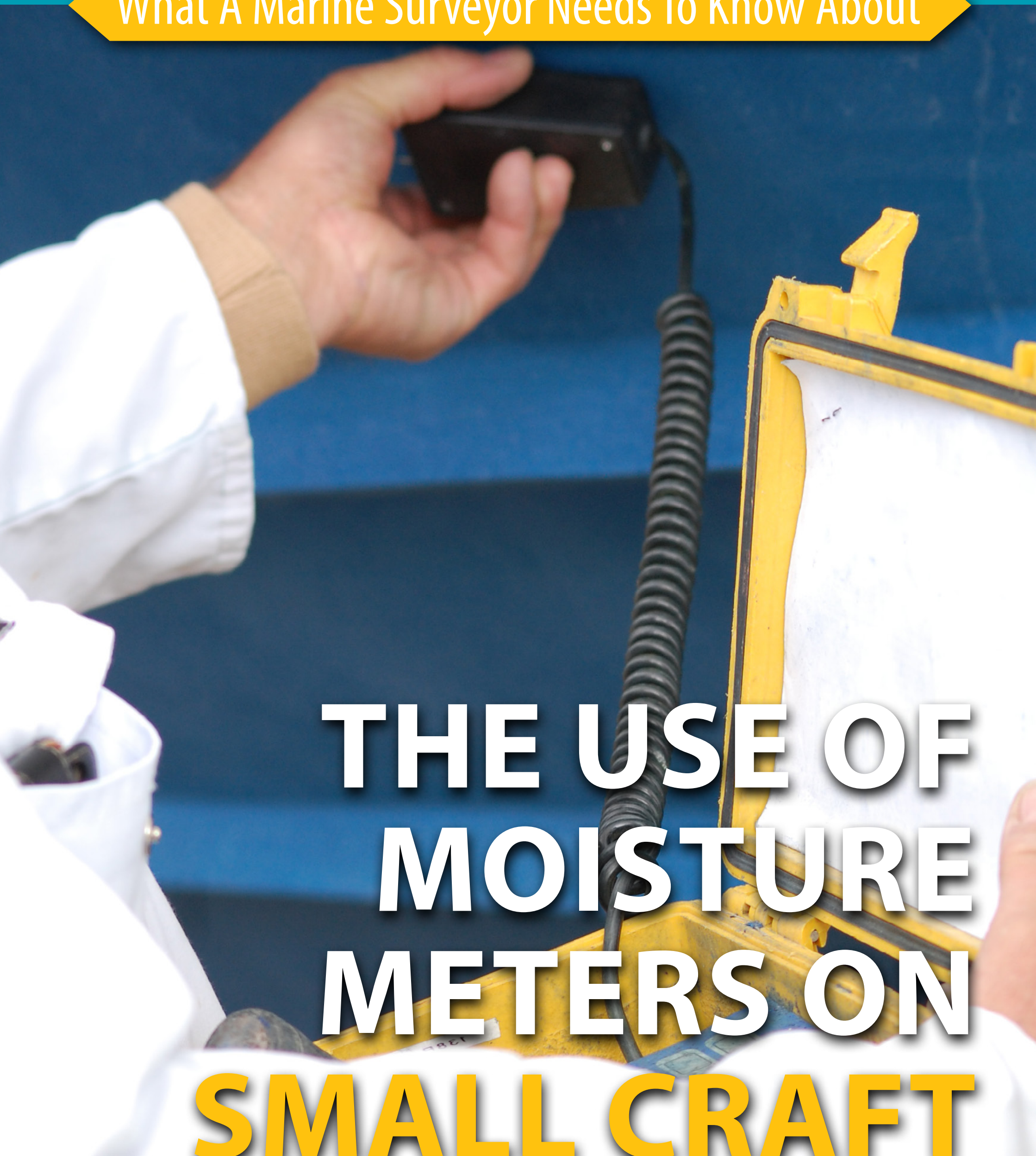

THE USE OF MOISTURE METERS ON SMALL CRAFT

by JEFFREY CASCIANI-WOOD

ABOUT IIMS

The International Institute of Marine Surveying (IIMS) is an independent, non-political organisation promoting the professionalism, recognition and training of marine surveyors worldwide.

The IIMS defines marine surveying as: "The service provided to maritime and transport organisations in general and the production of guidance reports for all other bodies connected with maritime operations or maritime trade".

The IIMS is the professional body for marine surveyors and has a worldwide membership of around 1,000 individuals in over 100 countries. It is the largest organisation of its kind and seeks to represent its industry to government and non governmental organisations such as the International Marine Organisation (IMO), Coastguards, insurance companies and ship owners.

The IIMS provides a range of services to its members, allied organisations and to the wider shipping and boating world, including:

- **Maintaining a comprehensive searchable database of marine surveyors via the website or marine surveyor search app**
- **Professional training courses for marine surveyors**
- **A distance learning education programme in marine surveying**
- **The Report, a quarterly publication highlighting key marine surveying topics and news**
- **Conferences and meetings internationally providing a place for the marine surveying industry to meet**
- **Acting as an MCA approved vessel coding authority duly authorised by the Maritime & Coastguard Agency**
- **The Marine Surveyor Search App**

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CONTENTS

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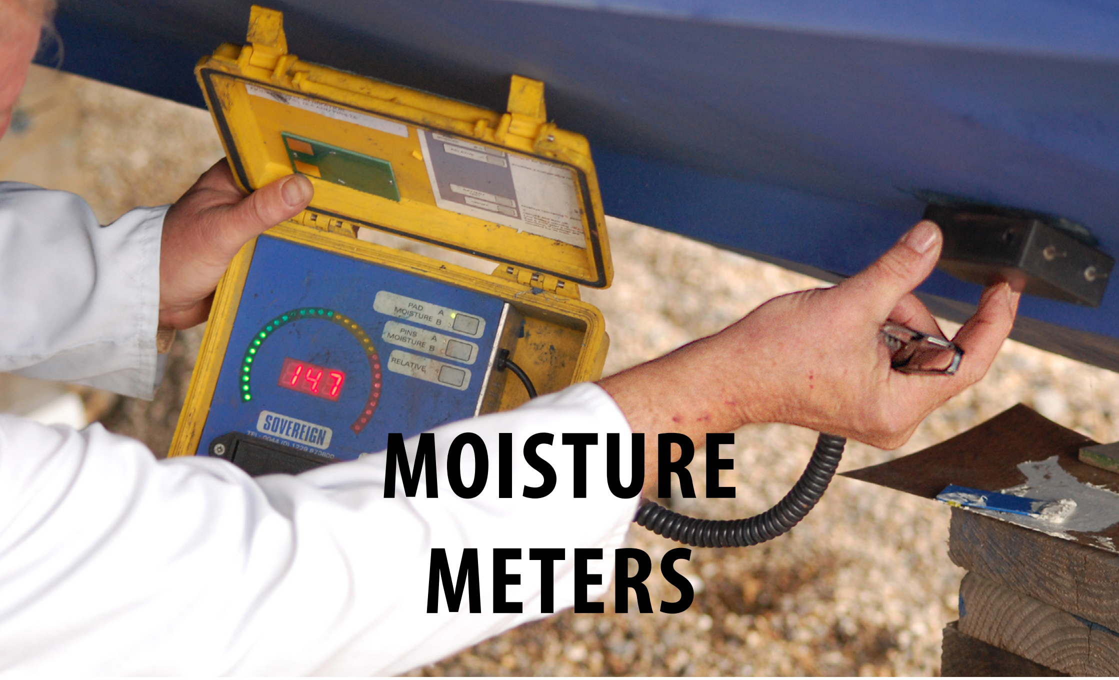


MOISTURE METERS

In experienced hands moisture meters are undoubtedly an invaluable tool, but….

Which Moisture Meter? – Tony Staton-Bevan – PBO No. 319

There is no direct correlation between hull moisture content and laminate condition

The Osmosis Manual - Nigel Clegg

If the only tool you have is a hammer, you tend to see every problem as a nail.

Abraham Maslow

Moisture Measurement - Introduction

These days it is *de rigueur* for a marine surveyor inspecting a fibre reinforced plastic boat to use a moisture meter and the first thing to know about moisture meters is that they do not actually measure moisture. What they do measure is conductivity. A Tramex meter (a popular model with both marine surveyors and boatyards) invariably shows a very high moisture reading on the solid and absolutely dry glass top of a living room coffee table as it is measuring the presence of minute traces of carbon (an electrical conductor) in the lightly smoked glass. The origins of the moisture meter lie in the building and construction industries and the original scale was based on the water content of brick and stone work. The scale has largely remained unchanged. There are a number of these machines available in the market and they were first introduced into the marine industry for checking how an frp hull had dried over time prior to rebuilding for osmosis treatment and for that they remain a useful tool. They are also used to check for moisture below a surface that looks dry.

Moisture Measurement – The Meter

Electrical moisture meters have an enormous advantage for the general survey as they are clean and non-destructive but they do have limitations and they do **NOT** *quantitatively* measure moisture on/in hull substrates. The majority record electrical resistance between two applied electrodes or capacitance and, more recently, some measure the reflection of radio frequency emissions from the meter. Moisture, together with one or two other materials, affects these properties. Thus, such meters can reflect the presence (or absence) of moisture and/or other factors which may be present. The actual readings also depend on the area of contact of the probes/electrodes with the substrate and the marine surveyor will obtain much higher readings on a material where the probes can fully penetrate than on a similar material with similar moisture factors where the probes cannot do that. Therefore, he should not try to make *simple* comparative readings between substrates as the meters are qualitative and may just be reflecting the probe contacts and nothing else. It must also be fully appreciated that electrical moisture meters, especially conductance ones, are very sensitive to very small amounts of free moisture and/or certain types of soluble salt contamination. For example, free moisture contents of less than 0.1% can result in high meter readings. The actual reading of the instrument has an optimum level which is a function of the frequency of the detector.

It is essential to appreciate the fact that on hull substrates the readings may not always reflect moisture alone. For example, contaminant hygroscopic salts such as chlorides even in very low concentrations, especially under conditions of high humidity, will cause moisture meters to respond quite positively. It is also possible for the material itself to be significantly electrically conducting but that is rare and is generally quite evident to the investigator from the unusual distribution of readings. Nevertheless, the factor should be borne in mind but, most importantly, where the meter records zero readings the surface is both dry and uncontaminated. The readings obtained from hull surfaces should be read as 'per cent full scale deflection' of the meter needle depending on the type of scale provided. The fact the meter does not record a quantitative measurement is of little consequence as the marine surveyor's diagnosis should be based on the overall distribution of meter readings and not so much the actual reading itself. An electrical moisture meter should be used to plot a profile of readings which involves recording the pattern and distribution of surface readings. It is the pattern and distribution that gives an indication as to the problem if such exists. Often the marine surveyor will find that boats that have been laid up for some time are wetter inside due to condensation and he will find water in the bilges and lockers and that also adversely influences the moisture meter readings.

For a normal run of the mill survey of an frp hull, however, they have only a very limited, and frequently misunderstood, application and the marine surveyor should clearly understand that they can, and do, give false readings and are not foolproof. He should also clearly understand that moisture meters cannot:

- measure the moisture content of an frp hull as a percentage of its dry weight and the readings should never be described as such,
- distinguish between ordinary water and water that has been mixed with other chemicals to form a different, perhaps denser, fluid. That means that they cannot

be taken to indicate that the process of osmosis is beginning before any blisters are evident. Unsurprisingly, that is a common mistake,

- determine the time period over which a wet hull will dry out,
- determine whether or not a hull will develop osmotic blistering or has any other related defect such as hydrolysis.

These points should be borne in mind and the marine surveyor should understand and make it very clear that diagnosis of matrix condition should never be made on moisture meter readings alone. Experience will soon show that very often moisture meters simply confirm the obvious – that a boat that has been in the water is wet. The marine surveyor must know that high moisture meter readings *per se* are not disastrous and have to undergo a number of corrections before they can give any indication – even then a not very reliable one – as to the moisture content of the hull. He should also keep in mind at all times the quotation from Nigel Clegg's *Osmosis Manual*. Further, however many moisture meter readings are taken, even if taken, analysed and compared in accordance with any published standard, they will not tell even the most assiduous marine surveyor whether or not the hull he is surveying has any propensity to blister.

Moisture Meter Types

Moisture meters used for marine surveying work are, or should be, of the capacitance or impedance type. The most common brands in general use are the Sovereign, the Tramex Skipper and various types of Protimeter. Other equally valid brands may also be found. What all of these meters have in common are that they use an alternating current as opposed to the direct current used in resistance type meters. Resistance type meters have prongs that are inserted into the surface under test and are unsuited for marine survey use on frp vessels as they damage the gel coat although they can, and/or should, be used on wood. The earliest electronic instruments used to determine moisture content were derived from the building industry. These were originally scaled to show the relative moisture content due to rising damp in brickwork and masonry and it is a curious fact that modern instruments used in surveying frp boats still use the same scale. Modern meters used in the marine industry are in essence of two different kinds:

- the pin meter
- the pad meter

The somewhat old fashioned pin meter is fitted with a pair of sharp pointed probes and works on the principle of conductivity. The underlying assumption is that the moisture content of the laminate affects the resistance of the surface between the probes. Since, however, one has to press the pins into the surface, this act, as stated above, causes damage to the gel coat and actually increases the probability of moisture entering into the matrix by a small amount. For those reasons the pin type of meter should not be used on the surface of an frp boat. However, if the gel coat has been removed for whatever reason, there is nothing to stop the marine surveyor from using such a machine on the underlying matrix although, even there, the author does not recommend that. That type of machine should really only ever be used on wood. The units furthermore took no account of the widely varying resistivity or conductivity of the various liquids to be found in frp laminates resulting in inconsistency and general meaninglessness in the readings.

The pad machine sensor consists of a transmitter and a receiver which sends and receives a high frequency radio signal between a pair of electrodes pressed against the laminate surface and which penetrates the material under test. The instrument works on the principle that an increase of moisture in the laminate causes an increase in the capacitance of the material under test and this is interpreted by means of a scale to give an approximate relative value of the moisture content. The radio waves do not harm either the resin or the reinforcement but the strength of the received signal is proportional to and measures accurately the local permittivity on an arbitrarily numbered inverse logarithmic scale arbitrarily numbered 0 to about 25. For a given system of conductors, the ratio of the permittivity to the potential difference in volts is a constant and the ratio q/V depends only on the geometry of the system. The ratio is called the electrostatic capacity or capacitance C. Thus:

	C	=	q/V	farads	(1)
where					
	C	=	capacitance	farads	
	V	=	potential difference	volts	
	q	=	permittivity or dielectric constant	-	

The moisture meter with a standard 9 volt battery and, in fact, measures q. The basic assumption underlying this machine is that q is affected by and the reading is directly proportional to the moisture content of the laminate. All makes work on the principle that the presence of moisture affects the impedence in the a.c. radio circuit. While that is true, as experience will show, the impedence and, hence, q is also affected by a number of other items both internal and external to the laminate. Unless that fact is recognised and acknowledged by the marine surveyor, moisture meters can be, indeed frequently are, a snare and their readings a delusion.

The pad machines of the Sovereign and Tramex types are of the capacitance type. The **A** Scale, which is the one usually used, carries numbers purporting to be percentage moisture in the surface measured but do not give the basis of the percentage. As the machines were originally designed for the measurement of moisture by house surveyors the scale has been calibrated to roughly represent the moisture percentage by weight in standard brickwork. It cannot be transferred directly to plastic surfaces as the dielectric constants between the two materials are vastly different. The instruments are fitted with a pair of concentric metal ring electrodes fitted into a scanning head connected to the instrument by means of a length of coaxial cable. The instruments are fairly sensitive but, because the electrodes are only about 2.5 mm apart the effective practical depth of field is only about 1.5 to 2.0 mm. They also operate on a rather high operating frequency and that means that the readings tend to be weighted towards moisture in the coatings or gel coat rather than in the structural laminate. That can be misleading particularly if the hull is coated with an epoxy based paint. Such coatings tend to retain moisture for long periods which also results in high readings.

Approximate Comparisons of Moisture Meter Readings

Nevertheless the Sovereign meter is a good unit and is still widely used in the profession. Because the unit is insensitive to surface moisture it is not considered to be suitable for an overall assessment of the laminate condition and should, in the author's opinion, be only used on vessels where the paint coating and probably also the gel coat have been removed. The marine surveyor should know that boats offered for survey are often covered with several layers of paint each absorbing and releasing moisture at a different rate. Measuring the matrix moisture content through such a complex paint coat is highly unlikely to accurately reflect the true moisture condition of the underlying laminate.

The Tramex Skipper range units are, these days, coming more into prominence and work by emitting lower frequency (14 kHz) a.c. signals from a pair of electrodes 24 mm apart in the body of the instrument. When no moisture is present the signals are insulated from one another and the instrument reads dry but with moisture present the resistance between the electrodes is reduced and the unit reads the moisture content by measuring the strength of the resistance between the signals. It suffers from the same drawbacks as other meters in the fact that anything that alters the local capacitance will be read as moisture content. It will also be found that when measuring at the same spot, if the meter is turned through 90°, the reading will sometimes be found to change. When testing frp structures the relative scale should be read and the moisture content of the hull calculated from the Calibration Chart supplied with the machine. Tests show that this machine will read somewhat deeper into the structure than the Sovereign machine and the author recommends that, in an important survey or one likely to result in litigation, both machines be used in conjunction with one another together with a Barcol hardness machine. With the Skipper unit the reading on Scale 2 should lie in the green area *i.e.*, under a nominal 14% moisture and any areas where the reading exceeds a nominal 15% should be given a closer examination.

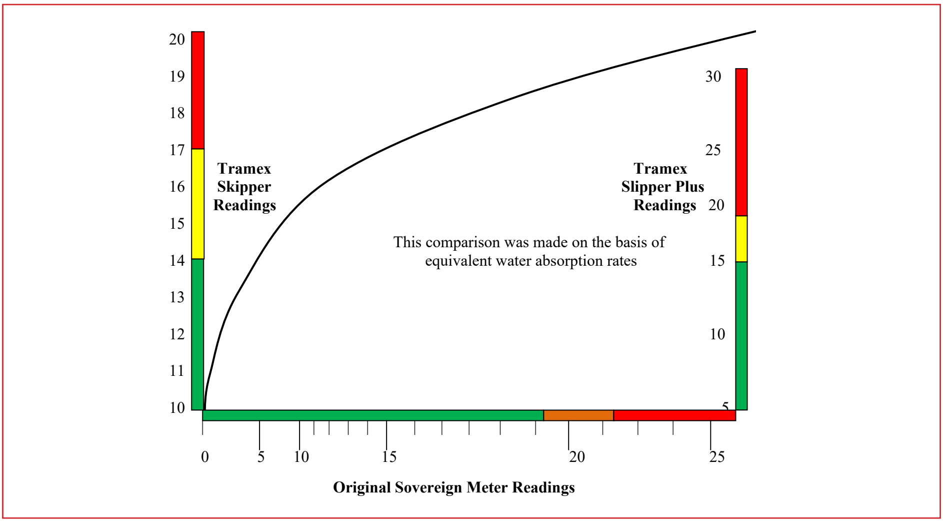


Figure 1 - Approximate Comparisons of Moisture Meter Readings

The spacing and shape of the electrodes that send and receive the radio signals have a significant effect on the readings delivered by the machine and these readings are also affected by the instrument's operating frequency. The operating frequency of the unit is not so important but the marine surveyor should know that higher frequencies tend to emphasise surface moisture and can often give totally false readings due to any colouring matter in the gel coat. The readings may, also, as well as being affected by ambient conditions, be affected *inter alia* by the local matrix density and resin/glass ratio, the local thickness of the gel coat, the presence of extra layers of reinforcement or structural items, chain cables, ballast, bilge water, copper, fuel or water tanks, gas cylinders, batteries and electrical wiring and similar items on the inside of the hull and even the static electricity in the marine surveyor's body and clothing and his own bone/flesh mass ratio. It is, however, not necessary to remove any antifouling or topside coatings back to the gel coat in order to use the instrument unless these surface coatings carry large amounts of copper or tin which also cause false readings. Boats coated with an epoxy coat also tend to have higher readings than the more common polyester. High readings, therefore, do **NOT** necessarily indicate the presence of excessive moisture and the machines cannot be used with any certainty whatsoever to predict the presence of hydrolysis, the process of osmosis or the onset or presence of the pox. The spacing of the electrodes also dictates the depth to which the radio signal can enter the laminate and, therefore, the depth to which moisture can be detected. Beyond that depth the response of the machine to moisture drops off very rapidly. That is an important point that is often ignored as the moisture that is likely to cause damage to the laminate is often deep within it and out of the range of the instrument. Neither can moisture meters be used with any accuracy on hulls containing boron or on hulls reinforced with carbon fibres as these substances have high electro conductivity. It is worth noting that the depth of penetration of the radio signal and the precise interpretation of the figures noted is a perennial source of discussion, not to say argument, among marine surveyors. Finally, the type, shape and distance apart of the machine's internal electrodes all have a significant effect on the level of actual readings given and, in considering the readings given later in this section, that fact must be taken into account when comparing readings taken with a different meter – even one nominally of the same make. It should also be mentioned that neither the original Sovereign nor the Tramex unit had a method of calibration and that meant that, in practice, the marine surveyor had to use both. Furthermore, experience soon showed that it was pointless to use the Sovereign machine to discover leakage round fittings on a heavily built sandwich deck as the top matrix layer may be dry whereas the inner core could be soaking wet and totally rotten. The machine would not detect the defect in the core. A similar restriction on the use but opposite effect of the Tramex unit was found with a lightly laid up hull with water in the bilge.

The Practical Application of the Moisture Meter

Moisture meters, it has to be acknowledged, are a form of fairly primitive technology but they have not yet reached a 'point and shoot' simplicity. That necessarily means that their use requires a certain amount of finesse and intelligence in operating them and interpreting the data they yield. The marine surveyor should also realise that moisture meters of any type, despite what is written on their dials, do NOT provide either an absolute or a percentage measure either by weight or volume of actual moisture content. At best the meters have to be regarded as giving only comparative tests. They are a guide only and must be used intelligently with that fact in mind.

With that in mind the marine surveyor should know that there are two reasons for using a moisture meter of an frp hull:

1. A test to compare the reading on one part of the hull with another which is the usual and most common test.
2. A test to compare the wetness number of the hull with a standard hull and, over time, to gain a history of the hull's water absorption characteristics with a view to *possibly* being able to predict the chemical breakdown of the hull.

The first test is a very subjective one and may be open to misinterpretation of the achieved readings. Much depends upon the skill and knowledge of the operator but any local increases in the readings whether they be gradual or sudden should be further investigated. As a guide only, the usual engineering criterion, which may not apply in every case, is that any readings outwith the plus three times the mean standard deviation range of the readings are suspect.

For the second test, bearing in mind that, in the author's view, the taking of moisture meter measurements form a scientific experiment, it is important that the readings be taken within a standard pattern clearly referenced to a clearly identifiable part of the hull so that the readings can be repeated at a later date. The number of readings taken should be related to the wetted surface area, the area of the topsides or deck as appropriate. That gives a method of historic comparison from which the true condition of the hull may be estimated with some degree of reasonable accuracy.

The readings should always be taken from the A or relevant %H_2O Scale NOT the Relative Scale. The latter is only for use with tables published by the manufacturers for use on timber. The basic scale is related to a standard timber – usually Douglas fir or Sitka spruce – and is NOT directly transferable to marine frp structures.

The prudent marine surveyor must stay current with newer technologies that may affect the use of moisture meters. Carbon fibre, for example, is becoming more common and any carbon fibre present in the hull will peg a moisture meter. Builders are also beginning to use the material in highly stressed areas such as the stem and chines and around sailing vessel keels. The tip marine surveyor should be aware that, if there is any carbon fibre strengthening on a hull there will be an immediate on-off change in the meter readings unlike the more gradual transition found when moving into an area of wet coring. Another modern construction element is the Hydropel gel coat sometimes used below the waterline which affects the meter in the same on-off light switch manner as carbon fibre. Certain high copper paints (particularly black) also affect the meter. Other exterior below waterline factors are the thickness of the paint and the ability of the exterior to dry in the course of the slipping - sloughing paints can be slow to dry as they are porous and hold on to the water longer.

Moisture meters are not particularly useful on a solid fibreglass hull but the marine surveyor should insist on using a meter on cored hulls - not only on the wetted surface and hull topsides but also on all other cored surfaces such as the stringers, transoms, cockpit soles and cabin tops and sides.

The marine surveyor has to know the details of the material with which he is dealing, the capability and characteristics of his meter including its depth sensitivity on the given material and, of the utmost importance, how to prepare the surface he is testing. He should also be aware that, due to delamination, he may, for example, obtain a dry reading in a wet core area on a deck.

If there is any condensate present, it should be dried and if there is any salt residue (even when dry it can peg a capacitance type meter) the area should be cleaned with no more than a spray bottle of fresh water and a towel. If the hull bottom is cored it is good practice to test it from the inside of the hull.

The Effect of the Ambient Conditions on Moisture Meter Readings

It is well known that moisture meter readings are affected *inter alia* by the prevailing atmospheric/hygronomic conditions and, in particular, it should also be borne in mind when taking and reading the wetness measurements that at ambient temperatures approaching zero (below about 5°C) moisture meters *of any make* become notoriously unreliable. It should also be noted that for the Wetness Measurements to have any validity at all, the ambient temperature corrected for any wind chill should be at least 5°C and the hull surface temperature also a minimum of 3°C above the dew point temperature. When using these machines, therefore, the marine surveyor should record the general weather conditions on the day on which any particular survey was effected. Any precipitation should be noted and the atmospheric ambient temperature, relative humidity and dew point temperature should also be recorded by an electronic digital hygrometer. He should also measure the strength and direction relative to the hull of the wind and the sun. The surface temperature on a number of points on both sides of the hull should also be measured and recorded. Without that data, moisture meter readings on their own are both misleading and worthless.

All these temperatures are relevant to a proper scientific analysis of the hull's condition and the understanding of the wetness measurements and without them the bare moisture meter readings are useless. The latest design of Sovereign meters includes sensors to read some but not all of these relevant parameters. All these figures are relevant to analysis. The raw data can then be corrected to a standard set of conditions and compared to a standard boat by the method given in Table 1.

Table 1

A Comparison of Moisture Meter Water Percentages

Sovereign Scale A	Tramex Percentage Scale		Water Percentage by weight
	Skipper	Skipper Plus	
1.5	-	-	
2	10	0.20	0.20
3	20	0.27	0.27
4	30	0.45	0.45
5	38	0.53	0.53
10	60	0.75	0.75
15	85	1.00	1.00
20	90	1.42	1.42
25	100	2.60	2.60

With the permission of the owners and the help of a local boat yard, the author carried out an experiment to record the wetness number on several boats over an eight month period over a number of fairly widely but regularly separated days starting from the day the boats were taken from the water. It was found, as one might expect, that the readings corrected for ambient conditions varied in time according to one of the solutions of the Newtonian differential equation, *i.e.*, the drying out was exponential and asymptotic to the x axis. It was from these experiments that he decided that the ambient corrections could be linear without a great loss of accuracy. Following on from that it was found that when the readings for a particular day were plotted individually, in general they often followed, again as one might expect, the usual mesokurtic curve associated with the Normal or Gaussian distribution and it was further found, however, that though the range of raw data lifted was often very wide, Pearson's coefficient of variation (also called the variance) rarely exceeded 35%. The value of the skew coefficient, which may be positive or negative without any apparent reason why, was also usually very low.

As a background to these experiments, the only known published data of a similar nature were those given in an article on the comparison of moisture meters in the article by a Mr Staten-Bevan published in *PRACTICAL BOAT OWNER* number 319, July, 1993 under the auspices of the Yacht Designers and Surveyors Association and Southampton University and are the only published experiments on this subject known to the author that could claim to be *scientific*. When the results of the writer's own experiments were plotted, the mean YDSA line as analysed out of that article was used as the basis as that had suggested a simple polynomial relationship and it was found that the results sat very closely on the line drawn from the YDSA experiments. It is interesting to note that despite the readings reaching and exceeding the top end of the scale on all of the machines tested the actual measured moisture content as a percentage by weight never reached three per cent. The mean results of the author's own experiments that were admittedly not as scientific as those carried out by the YDSA at Southampton are given in Table 1 and compared with the Tramex Skipper percentage reading. Most marine surveyors will be aware that often anomalous readings taken in the field can be put down to the machine feeling the presence of extra thicknesses of lay-up, water tanks, piping, wiring, gas bottles and even the presence of the marine surveyor's own body *etc*.

Because of the wide range of largely unknown factors that can influence the performance of a moisture meter many marine surveyors often simply report the figures of the meter readings giving the impression that they are apparently unwilling or, perhaps, unable to provide a comprehensive explanation of the results and frequently, when he does comment, the marine surveyor's advice is often vague. That, of course, leaves the boat buyer with more questions asked than answered. It is, of course, common knowledge among experienced marine surveyors that moisture meter readings can be difficult to interpret at best and totally unreliable at worst. That is not the meter's fault. Rather it is the result of the very presence of these many unknown factors and, sad to say, often the manner in which the marine surveyor uses his meter. The author must also comment that of all the meters he has used over many years of practice none of them provided any information for their use on composite boat hulls the notable exception being the Tramex Skipper unit and even that does not give any guidance as to the reading's interpretation.

It is known that all frp laminates, whether cored or solid, contain millions of voids partly due to air entrapment and that there existed problems without gassing during cure plus just plain, poor quality workmanship. Further, the skin out layer of chopped strand mat just inside the gel coat is well known to be extremely porous and to absorb large amounts of water. That had been directly linked to the cause of gel coat blistering and is, by far, the major cause of most water absorption by laminates. It is also believed that structural laminates, those containing the major structural fibres are far less prone to water absorption.

That left the question as to what is the precise location of the moisture or whatever that the moisture meter was apparently reading. Was it in the gel coat, the skin outer layer, the structural laminates, the core or all of these? Clearly, when working on a boat hull, the marine surveyor has no immediate way of knowing the answer to that question. With the introduction of cored boat hulls perhaps the most critical question that the marine surveyor needs to answer is whether or not water has entered the core as that can be fatal.

The author then carried out a number of random tests on boats just lifted from the water but with bottoms that are superficially dry and demonstrated to his own satisfaction that residual moisture within paint layers, the gel coat or skin out layers often produced erroneous readings. That was determined by taking readings randomly on boat bottoms that had been sitting on shore in the same yard for varying periods of time and which produced, on average, much lower aggregate readings. Even so, large numbers of the boats that had been ashore for some time still gave average meter readings which suggested severe hull wetness. What was notable about the latter group, however, was the fact that the higher readings tended to be toward the keel whereas the higher readings on the boats that had just been hauled from the water were more uniformly spread over the wetted surface. The conclusion was inescapable: that metering boats just lifted from the water was totally unreliable and prone to deliver false readings. It was that fact that caused the author to remember his school physics and maths lessons and to remember Newton's differential equation and to estimate the constants.

The next question to be answered was how the gel coats behaved. Were some rather than all gel coats more prone to water absorption and was there a difference between gel coat below the water line compared to that in the freeboard area? Tests were performed under varying climatic conditions. It was soon discovered that moisture meters will not read frozen water; if one is placed on a piece of dry ice the reading were always found to be close to zero. Both humidity levels and temperature were proven to have a small effect but one that that could be estimated linearly.

The decks of a number of boats were also tested immediately after rainfall and here the wet gel coat was superficially dried and measured immediately. The author was somewhat surprised to find that the readings were almost always fairly low even on old boats with well worn gel coats. From that it was concluded that gel coat in the freeboard area and that is not subjected to water pressure in fact absorbs very little water. Thus, it was further concluded that the use of a meter to detect a wet core beneath the outer skin on such items as decks and superstructures would produce fairly reliable results.

Clearly, underwater surfaces should be cleaned of all forms of marine growth – barnacles, slimes, grass *etc*. – before undertaking a moisture meter test but the cleanliness of the surface above the waterline also matters. Salt and dirt that accumulates over time on all of the boat's surfaces are, by nature, abrasive. It is a common practice to sweep the meter's pad over a surface to explore general moisture content but, with a dirty or salty surface that also has the effect of sanding off the boat's gel coat and destroys the surface of the meter's pad. That is especially so on painted surfaces. The resulting repairs can be expensive. It was also found during the author's noted tests that salt and dirt residues affected the meter readings strongly such that, on an apparently dry deck or hull, salt residue will affect readings by as much as 40% and wiping the surface with a clean cloth sufficiently to remove the residue meant that the reading was affected by usually less than 10%.

The marine surveyor might be forgiven to think that capacitance meters would read poorly on rough uneven surfaces such as the insides of hulls or non-skid decks but experience shows that, in fact, the meter reads remarkable well on moderately rough surfaces although it is advisable that he should try to obtain the smoothest surface possible upon which to take accurate readings. The pad must be cleaned before the test with a dry, soft cloth and it is a good idea to test its surface with one's hand before trying onto the boat's gel coat. A mild spray cleaner can be used on the pad but must be allowed to evaporate before testing the hull. When using the place and read method, the marine surveyor should frequently clean the pad's surface with a soft cloth or with dry kitchen paper. That helps to reduce abrasion of the pad's surface. The pads have to be replaced for such wear and tear (when they begin to look like a bald car tyre) at about five year intervals.

With epoxy, as with other plastics, the readings are dependent on how long the vessel has been out of the water. If they are measured within 24 hours of being in the water it is often the case that moisture readings are slightly elevated on epoxy coated hulls as the rough surface of the epoxy holds moisture longer than a smooth gel coat surface due to the epoxy having a higher adsorption capability and a greater surface roughness. Antifouling coats to some extent smooth over the roughness but can make matters worse by creating moisture traps between the two surfaces. Many meters will read both on shallow and deep into the laminate so it makes little difference if the readings are taken from the inside or outside of the vessel. It is always a case of interpreting the moisture reading results taking into account the vessel's construction and the ambient conditions in which the readings were taken. Again, however, it depends on how long the boat has been out of the water. If it has been out for months taking readings through the antifouling on a dry day has little to no effect on the results but if the readings are taken on a wet day with high humidity then they go up and it is necessary to remove the antifouling coating and to wipe the hull surface with a dry rag before taking the readings.

The Interpretation of Moisture Meter Readings

First it must be stressed that the analysis method mentioned does not give a method of interpretation of the results but only a method of reducing them to a standard comparative figure using the standard mathematics of engineering statistics. Regretfully and all too often engineers in general and marine surveyors in particular seem to regard statistics in much the same way as a drunk regards a lamp post – more for support than illumination. He must not regard statistical techniques in the somewhat disparaging way as merely number crunching. Statistics are a very useful tool and the marine surveyor is recommended to learn at least the basics of the skill. It was also found during the author's experiments, and this must be stressed, that there is no direct relationship between laminate moisture content and laminate condition and a high level of readings on their own does not necessarily mean that the laminate is suffering damage due to penetration by either permeation or the process of osmosis or chemical or structural breakdown induced by hydrolysis. Moisture meter readings, therefore, cannot by themselves and in the absence of other information be used to make a diagnosis of structural breakdown. The real danger sign, in the author's view, is when readings taken at successive times remain persistently high and do not fall appreciably within two or three weeks of lifting the boat from the water in accordance with Newton's exponential law as that possibly indicates that the laminate is retaining breakdown products and justifies a more detailed examination such as the taking of surface hardness measurements by a Barcol meter, core samples and similar actions. For moisture meter readings to be used for diagnostic purposes, therefore, a regular series of readings in the same places on the hull must be taken over a period of several weeks.

The indicated figures in Table 2 opposite may be used in the absence of other information as a good guide to allowable figures but should be compared to a known dry laminate for reference. It is usual, and convenient, to measure the vessel's topsides for that purpose but even that is not always reliable. It is usually assumed that, unless the laminate has a saturated core, there is a direct comparison between a dry and a wet laminate. Some yachts known to be over wet, however, have topsides with a high moisture content - which, incidentally, has led to the topsides blistering – and the marine surveyor should be aware that immersion is not a necessary criterion for water absorption although it is sufficient. Where possible, therefore, the marine surveyor should take readings from a new vessel or one known to be in good condition for use as a benchmark. If, over time, the readings below the water line, change rapidly, compared to those in the freeboard area, then that may be an indicator that the paint coatings are excessively wet and a set of readings should then be taken in areas where the paint coats have been removed.

Table 2

Comparison of Wetness Numbers

Wetness Number	Condition
Below 8	Satisfactory
8 to 12	Fair to Good
12 to 18	Suspicious
Above 18	Poor

When the surface of the hull has been properly prepared for moisture meter examination, the readings on the hull bottom should fall rapidly over time in accordance with Newton's law compared to those on the topsides. If that does not happen, or if the readings rise and fall in sympathy with the ambient temperature and humidity, then it is likely that the hull laminate still retains a significant glycol content. From the author's experience, marine surveyors may be expected to pronounce an opinion on boats that have been out of the water anything between half an hour and several years. Obviously the time out of the water affects the readings as the hull has had time to dry out (including the process of reverse osmosis) although the author could find no published data on such a drying out effect. Moisture meter readings taken on a boat just lifted from the water will be high even if the hull surface is cleaned off with acetone and taking them then is utterly pointless. The length of time that a vessel has been afloat also has a significant effect on moisture absorption and meter readings.

How deep into the laminate a meter will read is, of course, a critical question for marine surveyors but to which the author's tests produced no satisfactory answer largely due to the fact that the quality and consistency of the material being tested could not be known. However, the findings did reveal some probably important results that included the fact that the denser the material, the more capable the meter was of reading through it. A meter will not read water through any kind of dry core as the entrapped air space blocks the instrument's signal. The implication of the discovery was that false readings might occur if the meter is placed over a void, a delamination or an area of resin starved laminate. The material behind such an area may well be soaking wet but the meter will not pick it up on that particular spot. Such random false readings can be minimised by using the meter in a scanning mode. *i.e.*, the marine surveyor should not take spot readings but should move the meter around the chosen area in a circular action. The meter works very best by dragging it slowly across the surface. The problem in trying to answer the question stems from the fact that it is not possible to determine whether or not the meter is reading moisture behind or within the laminate. That is the also fundamental difficulty with trying to meter hulls in order to ascertain the wetness of the cores. However well used the meter cannot tell which part of the hull is wet, the skin, the core or both. A further factor that affects that, with immersed hull areas, is that the water pressure exerted against the skin is proportional to the draught. That fact also probably explains why wetter readings are usually found in the lower parts of the hull.

Fortunately, there are some techniques by which the meter can be made more useful and the first and most important of these is to cross check readings taken on the outside of the hull by, where possible, taking counter readings on the inside of the hull. The inner skin of the laminate, of course, is never submerged and should, therefore, not be wet. Thus any wet reading obtained on the inside of the skin – after assuring that the outer surface is clean and dry – will more likely to be a positive indicator of a wet core. That is bolstered by the fact that the inside of the skin is usually better ventilated than the outer skin. Another, though much less reliable, method is to search for areas on the hull bottom with low readings on the assumption that, if the hull skin has the same overall absorption, the bottom readings should indicate the same overall wetness. If there are a number of areas that give relatively low readings that shows a fairly strong indication that certain areas of the core may be wet. That should be confirmed by doing at least some limited testing from the interior in those places where the shell is accessible. In addition to the items mentioned above false readings can also be produced by a number of conditions that include excessive amounts of CSM in the skinning out layer, the use of absorptive fairing materials, ablative bottom paints and paints containing metals and oxides of metals with copper topping the list of metals. The marine surveyor should also be careful and sceptical of readings taken around keels, struts, rudders and other areas that may contain fairing.

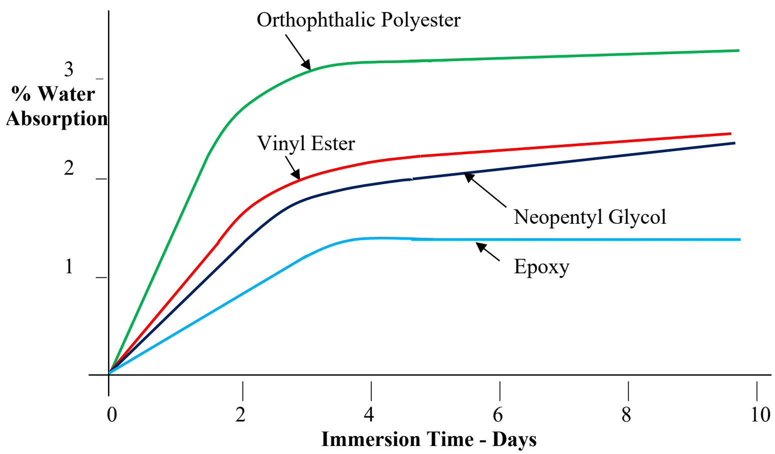


Figure 2 - Typical Water Absorption Curves

Figure 2 shows some typical water absorption curves and it should be noted that drying out curves are similar but are vertically reversed. Both are solutions to Newton's differential equation.

Water in the bilge or trapped in other hull spaces will definitely affect readings taken on solid laminates. On the other hand, water cannot be detected through a dry core of balsa or foam whatever its thickness and the marine surveyor should look out for such items as top hat stringers that may be full of water, bilge sumps and the like. Before metering the outside of a hull, he should familiarise himself with the structure and whatever is on the inside and where and he should keep in mind that the meter might read right through up to 12 mm of solid matrix even though the matrix itself is dry.

False dry readings can also be obtained after a core has completely rotted or otherwise broken down. Under such conditions there may be no moisture saturated material in contact with the outer or inner skin and the meter will read low when, in fact, the core has wasted away. That has proved to be a problem with older boats that have very thick skins with low deflection ratios. The marine surveyor should know that such badly wasted cores will usually leave other telltale evidence such as brown water stains leeching out of the laminate at various points, particularly at the low point of any structure such as a deck or cabin top. The marine surveyor should also know that high moisture readings are not necessarily a precursor to gel coat blistering and to understand that high moisture (if that is the cause of high meter readings) only *may* result in blistering. It has long been known that boats built with good quality material have little tendency to blister whereas low quality resin combined with excessive use of CSM in the skin out layer is often a primary factor in blistering.

Sovereign Quantum Marine Moisture Meter

While the older Sovereign unit is still a valid instrument it is now somewhat dated. Its great drawback was the shallowness of the depth to which it could measure a given laminate. The Tramex unit measured to a depth of about 10 mm while the original Sovereign measured to only about 3 or 4 mm after which ts effectiveness fell off sharply. The makers of the Sovereign have now produced a new unit called the Sovereign Quantum Marine Moisture Meter which, according to the maker's blurb, was specifically designed for marine use. It includes a built in self calibration facility and both near surface and in depth readings can be taken and the moisture content of a laminate is displayed as a numerical read out on a scale of 1 to 100. The instrument allows the operator to establish a datum such that comparative readings can be displayed as above or below the selected datum. The instrument measures both the ambient air temperature and humidity and these are automatically compared to enable the instrument to display the local dew point temperature. Spot surface temperature readings can also be taken to warn the operator of potential condensation problems, misleading or spurious moisture readings or unsuitable conditions for commencing coating applications. A bright traffic light series of LEDs display instant visual information and below that a numerical readout is available for recording specific readings. These units may well become the industry standard in the foreseeable future. The Table 2 has been distilled from the maker's published information and is based on their software Series 3-8. Where the readings are considered to be unacceptably high it is recommended that a further set of readings be taken in the same spots after a suitable drying out period has elapsed. As a rule of thumb, experience shows that the readings will fall by about one range in Table 3 opposite within three or four weeks and two ranges after about six months *i.e.* in accordance with Newton's law. Unless serious delamination or hydrolysis has occurred the amount of moisture in the hull should then be minimal. If the readings remain high then an acoustic (tap) test should be carried out. Where there is no visible evidence of a problem such as blistering but the readings remain high then the service history is particularly relevant and should be studied for records of previous remedial work has been undertaken or a special coating has been applied. The marine surveyor should note that the original Sovereign and Tramex meters indicated their readings by a needle and coloured dial. The more modern Sovereign and Quantum units use a digital read out which is possibly more accurate. He should, however. be aware that such accuracy is most probably something of a delusion.

One final word on this subject. If the moisture readings on a hull are high after the vessel has been out of the water for a week or more but there is no visible sign of blistering it is very unwise to recommend any remedial treatment to the gel coat as moisture content has no direct relationship with the condition of the laminate. Old boats, for example, frequently have high readings but no blisters. If the blistering is due to hydrolysis and subsequent osmosis, moisture will be found in the laminate and the hull will exhibit high readings. That, however, is not conclusive evidence that hydrolysis/osmosis is occurring or about to develop as the high readings could be due to other causes such as:

- water ingress to a core material.
- water present in large matrix voids.
- water in poorly wetted out areas of the laminate.

Use of Moisture Meters on Wood

When used on wood resistance type meters effectively measure the moisture content of the wettest part of the wood with which the bare parts of the bare electrodes are in contact. Capacitance meters whether used on wood or frp, effectively measure to an arbitrary scale the highest moisture content within the field penetration of the unit tested which may be up to 25 to 50 mm in depth in general purpose meters. Resistance type moisture meters used on wood generally have an operating range of between 8% and 25% moisture content on a dry weight basis. Below a moisture content of about 10% the resistance decreases too rapidly with only very small changes in moisture content to allow that to be used to the same level of accuracy. As the timber approaches the fibre saturation point between 25% and 30% moisture content, meter readings become unreliable for the opposite reason. In the same circumstances capacitance type meters do not have a problem at low moisture content. A few of the resistance type meters and most of the capacitance type are capable of giving an approximate reading of useful indicative value above the fibre saturation point but such readings should not be accepted as accurate without specific calibration evidence. The marine surveyor will also have always to consider the accuracy required of the meter. For general use in timber above 20% moisture content a meter should give a reading within ±2%; in timber below about 15% moisture content the reading should be within about ±1%. Attempts to calibrate to a finer accuracy will generally be a wasted effort but with continual use the marine surveyor should achieve reasonably greater accuracy. Boats, by the natural environment, are subject to changes in the moisture content which will result in a moisture gradient within the timber that may persist for a considerable time. Wood that has been dried will be wetter in the centre than on the surfaces. Dry wood that has been wetted by sea or rainwater will be the reverse. Wet wood being allowed to dry in air will establish a gradient as the surfaces dry. Dry wood in a damp atmosphere will do the same but in reverse and more slowly.

Table 3

Interpretation of Sovereign Quantum Moisture Meter Readings

<table>
<tr><th>Reading</th><th>Probable Interpretation</th><th>Examples</th><th>Comments</th></tr>
<tr><td>0-15</td><td>The shell is quite dry and in an acceptable condition</td><td>Modern yacht with epoxy protection from new. Yacht with gel coat removed after a drying out period prior to application of an epoxy treatment.</td><td>Establish the minimum before proceeding with any treatment.</td></tr>
<tr><td>16-20</td><td>Some low level moisture present but which may probably be ignored</td><td rowspan="3">1. Yachts with isophthalic and vinyl ester gel coat resins after the initial lift out but the readings will quickly reduce depending upon ambient conditions.
2. Older orthophthalic resins may take longer for the readings to reduce.</td><td rowspan="3">Take the following three steps
1. Use both shallow and deep modes to make comparative readings.
2. Use the dew point facility and thermistor sensor to identify potential condensation problems and spurious readings.
3. Monitor at a later date to confirm the readings.</td></tr>
<tr><td>21-30</td><td>Medium readings but those at the top are at the point where moisture related defects may have started but are not yet detectable.</td></tr>
<tr><td>31-45</td><td>High level readings where the presence of otherwise non-detectable moisture related defects are a significant risk.</td></tr>
<tr><td>46-60</td><td>Readings at this level must be considered to be very high and will usually be accompanied by physically detectable signs such as blistering. The readings will probably be considerably higher if the machine is changed to deep mode.</td><td rowspan="2">Blistering may be visible and the gel coat may be starred or cracked.
Susceptible location and age of boat.</td><td rowspan="2">As above
Experience and knowledge of the particular construction and boat’s history are essential before any conclusions may be reached.</td></tr>
<tr><td>61-100</td><td>Very high readings indeed and indicative of laminate deterioration and almost certainly accompanied by obvious osmotic blistering and other physically detectable signs. Again, the readings will probably be considerably higher if the machine is changed to deep mode.</td></tr>
</table>

One small point about a resistance meter is that it is possible to drill small holes into the underside of a wooden deck, for example, and use insulated deep wall probes to read directly off the wood or, with an frp boat, the balsa core. The technique works well when trying to confirm water intrusion into core or if the marine surveyor thinks that the meter is skewed by surface anomalies. On solid wood, the technique helps confirm a rot pocket, say, deep in the rabbet along the stem. It is also possible to use two stage approach locating possible problem areas with surface scan, then confirming as described with probes. The procedure is both respectful to the boat and also demonstrates that surface meters are not black magic. Some woods like pitch pine or oak absorb lots of water without which they dry up. A dry pitch pine plank may well go off scale with moisture content but that does not mean it is rotten. Moisture meters of any kind should not be used below the waterline on a wooden boat as the salt alone will cause a very high reading. The method suggested, however, means probing timber above the waterline that could be subject to rainwater intrusion. Lifting paint and what might be a rot streak on the stem beneath the bow sprit or maybe deck beams that may be deteriorating at the faying surface with the decking may be the tip of the iceberg. If a probe shows that the moisture content is over 30% deep in the wood, that is above the fibre saturation point of the wood and a potential serious issue.

Moisture Meter Readings Mathematical Analysis

Bearing the above factors in mind it is logical to analyse the figures obtained in the field by statistical methods and to correct them by the factors and a mathematical (statistical) analysis. It is good general engineering practice that any readings outside $\pm 3\sigma$ be discarded as rogue spots. The method does not require knowledge of the underlying mathematics but only a simple knowledge of or the ability to do arithmetic. The underlying assumptions in this method are that:

- the hull, if sound and not hydrolysed, will have dried out in accordance with Newton's differential equation.
- the distribution of the raw numerical data lifted will follow the Gaussian or Normal distribution.

Under these assumptions it is possible to make simple numerical calculations to obtain what is called a wetness number (W_{mn}) and then correct that to a standard ambient temperature and relative humidity and then compare the final result to a standard number based on the degree of drying out since the boat was lifted from the water. The calculations are simple and the marine surveyor is recommended to use this method. A typical example for an frp boat is based on readings taken on the **A** Scale of a Sovereign type machine and on a Tramex Skipper machine. Upon completion of the calculations, the readings should then be interpreted in the light of Tables 2 and 3.

The marine surveyor should note that the method of analysis does not enable to tell whether or not the hull was suffering from matrix breakdown at the time of the survey or whether it is likely to do so in the near future. He should never rely only on electronic instruments and simple number crunching for his survey results but rely more on careful observation, realistic testing and that extremely rare and badly misnamed commodity common sense.

Independent Moisture Meter Trial Results

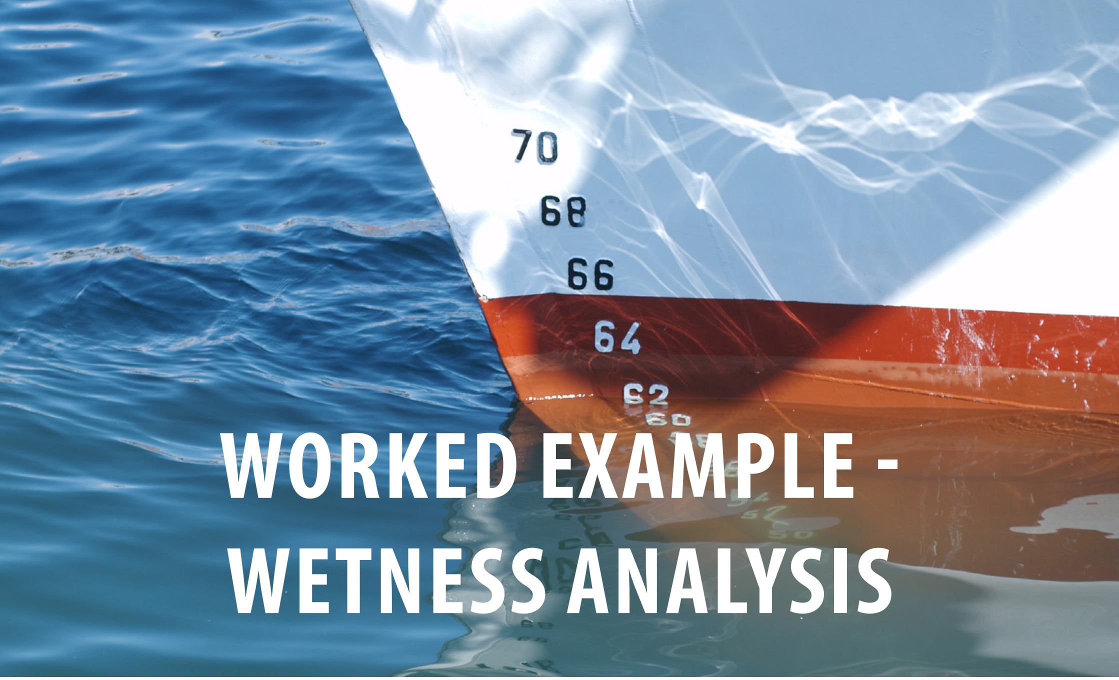
The Professional Boatbuilder No. 104 December/January 2007 given as a reference document above published an article (page 128) entitled *Demolition Derby* which makes very interesting reading for the marine surveyor. It describes how the American marine surveyor's organisation SAMS organised a meeting with a shipyard enabling a number of marine surveyors to carry out wetness surveys using their own equipment upon a number of what the article describes as bone yard boats. Each marine surveyor brought his own machine and carried out tests on grids marked out by SAMS on the boats and '*every commonly available brand of moisture meter was in play*'. Afterward the marine surveyors used a hole saw to cut out coupons from the boats to enable visual inspection of the laminates to take place. The whole experiment was done under the direction of an expert in marine composites. The article states that not only did some meters show moisture where there proved to be none but also others read dry where water was seen to be running out during the cutting operations. Some – unnamed – meters proved to be consistently less accurate than others and, finally, some hammers, depending upon who was using them, turned out to be as accurate overall as the best performing moisture meter. In another experiment a soaking wet sponge was held on the inside of a 3 mm thick hull but the applied meter – again unnamed but stated to be one of the most accurate overall - read dry.

The article asks the question "*Inasmuch as the meter couldn't detect a wet sponge on the other side of a thin skin, how could it find a soaking wet core in the real world?*" The question did not receive a reply in the article which, however, did suggest that conscientious marine surveyors should hang onto their hammers. A sentiment with which the author entirely agrees. The article is a salutary lesson to those marine surveyors who rely entirely on moisture meters when surveying frp boats. The meters are an addendum to the survey and can, if used incorrectly, turn out to be its *béte noir*. It has to be emphasised that it is simply not possible to predict whether or not a boat will develop the pox on the basis of moisture meter readings.

Use of Moisture Meters other than on the Skin

The marine surveyor should realise that use of the moisture meter is not confined to its detection of water absorbed through the gel coat into the hull matrix. In the majority of modern boats, the main structural bulkheads are manufactured from various grades of plywood not all of them really suitable for a marine application. They may often be found rotted due to water absorption and such rot becomes significant if the bulkhead is, for example, used as an anchorage for heavily loaded items such as chain plates when the load spreading effect would be seriously defective. Such rot and similar impregnation defects may be particularly found near or behind the boundary bondings. Water absorption may also be found at the bulkhead's heel if the vessel contains any quantity of loose bilge water.

A particularly nasty problem arises when a boat has sunk in the past and subsequently recovered. Such vessels are often rebuilt with huge sums of money being spent on renewing the electrics, soft furnishings, hull linings and overhauling the machinery *etc*. but the marine surveyor must understand that even very extensive drying out using dehydration equipment will not remove the moisture from the areas of plywood behind bondings and these will continue to rot away in the background. When a boat is surveyed and the interior and equipment found to be considerably younger than the hull the marine surveyor must suspect that she has sunk at some time and been rebuilt. He should then use the moisture meter repeatedly over all plywood areas knowing that there is no real reason other than an earlier submersion why any of these areas should be wet.



WORKED EXAMPLE - WETNESS ANALYSIS

There are lies, damned lies and statistics

Benjamin Disraeli

Method and Number of Wetness Readings

At the outset it must be emphasised that this method is not capable of predicting whether or not the boat under survey is suffering from or is likely to suffer in the near future from any form of matrix breakdown, hydrolysis, osmotic blistering or any other form of frp structural defect. It is simply a method of statistically analysing a set of raw data, correcting the result to a standard set of atmospheric conditions and then comparing that result to that of a standard boat that has been out of the water for the same length of time as the boat under survey. The interpretation of that result is then left to the marine surveyor's own knowledge and experience. The marine surveyor should also note that two readings on a given spot taken with the machine at right angles to its position when taking the first may differ wildly.

The following is a worked example of the method that, despite Mr. Disraeli, is based on the practical use of statistics. A statistically significant number of patches on the underwater surfaces should be chosen at random should be scraped clean (using a sharpened steel scraper) of surface coatings back to the gel coat. The cleaned areas must be thoroughly surface dried, taking great care to achieve a dry gel coat surface in any moist atmospheric conditions prevailing and specially examined and any obvious signs of osmotic penetration, blistering, wicking or any other defect noted in the areas tested. The rest of the bottom should then be examined both by touch and by eye and any osmotic or other type of blisters on the gel coat or any other signs of matrix breakdown by hydrolysis such as crust deposits noted and recorded with their approximate positions and extent. Moisture content readings must then be taken by means of a calibrated capacitance type machine (in the case of Sovereign machines on Scale **A**) on the scraped and cleaned areas mentioned above. The readings should extend well into the freeboard area and all over the bottom in areas where experience has shown that blistering – the visual indicator of structural breakdown is most likely to occur. These readings should be backed up by readings taken in the same spot using a Barcol hardness tester. A minimum number of readings must be taken on the boat's bottom and a relative number on the topsides. The minimum number of readings should be taken and the author calculates this minimum number from the simple Formula:

$$N_R = L_{WL}(B_{OA} + 2T_M)/3 \quad - \qquad (2)$$

where

N_R	=	number of readings	-
L_{WL}	=	water line length	m
B_{OA}	=	maximum beam	m
T_M	=	mean draught	m

This Formula gives approximately one reading per square metre of wetted surface but leaves the distribution of the readings to the individual marine surveyor's choice. The marine surveyor should remember that reinforced plastics materials are inherently heterogeneous and, for that reason, a large scatter of readings will be observed. Such scatter is mainly caused by the differences in hardness between the resin and the reinforcement material in contact with the small diameter indentor. According to the British Standard, the number of measurements should be such that the average result has a confidence limit of 95% probability level. It is suggested that the readings should be taken in bands round the hull approximately one metre apart and that there should be a minimum of three readings each side in each band. The readings on the topsides should be taken to give a relative dry base to the bottom readings and need only be about one third of the bottom readings in number. It must be pointed out that it does not follow that the dielectric constant measured on the topsides necessarily applies to the whole of the bottom of the hull. Neither should it be guaranteed that the measurements recorded at the time of the survey apply equally to those parts of the hull that were not measured at the time. During the taking of all these readings the instrument's calibration must be checked a number of times to ensure that it maintains its accuracy.

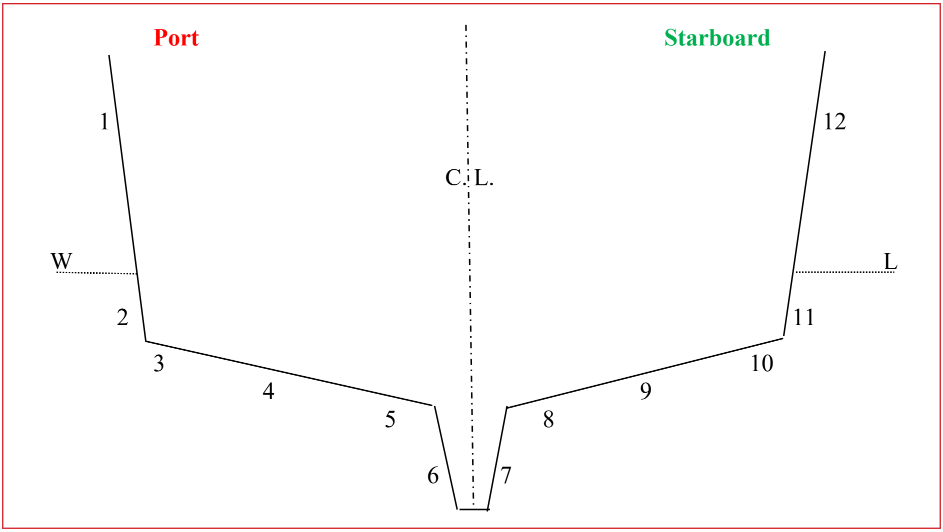


Figure 3 - Sketch of Boat's Midship Section showing Position of Readings

The Wetness Analysis

The following mathematical analysis is based on the results of a survey by the writer on a hard chined single screw motorboat which had no sign of blistering and which had the following principal dimensions:

L_{WL}	=	15.000	m
B_{OA}	=	4.850	m
T_M	=	0.785	m

Using Formula (2) above the *minimum* number of readings over the bottom should be:

$$N_R = 15.00(4.85 + 2 \times 0.785)/3$$

$$= 32 \quad \text{(to the nearest whole number)}$$

-

Local Wetness Measurements – Sovereign Meter

In the example given the author took some 70 readings on the bottom *i.e.* below the static waterline, and 14 over the topsides and these are shown in their relative positions on the sketch given as Figure 3 above. The instrument used was a calibrated Sovereign meter on Scale **A**. The sun lay to starboard during the survey and the wind was light, Beaufort Number 2 on the starboard bow. The mean ambient air temperature was 18°C, the mean relative humidity 58% and the hull surface temperatures 13°C to starboard 12°C to port with a dew point temperature of 8°C.

Table 4

Sovereign Moisture Meter Measured Readings

Position Ring	1	2	3	4	5	6	7	8	9	10	11	12	Position Ring
	Port								Starboard				
1	5	10	14	13	14	14	13	16	13	11	10	2	1
2	5	11	10	14	13	14	14	17	17	12	10	3	2
3	4	15	15	12	14	14	14	17	15	13	12	3	3
4	3	15	13	10	15	14	15	17	13	13	12	2	4
5	4	11	14	13	14	14	14	16	13	12	11	2	5
6	4	12	14	15	13	13	14	13	15	11	13	3	6
7	3	13	13	13	15	14	14	15	14	11	12	4	7

Analysis of Bottom Readings

For the Sovereign machine the bottom readings (shown in the Table 4 above as Position or Column 2 to 11) had a total range from 10 to 17 with a median of 13. The median is the middle number of the readings and laying the frequency of numbers out as in Table 5 below and taking the middle value can easily discover that.

Table 5

Bottom Reading Frequencies

Reading	10	11	12	13	14	15	16	17
Frequency	5	6	7	17	19	10	2	4

Wetness Calculation of Mean Value and Standard Deviation for the Bottom Readings

The arithmetic mean μ (sometimes given the symbol $\overline{x}$ pronounced bar x) and the standard deviation σ are calculated in accordance with the method set out in Table 5. From that, the arithmetic mean is the sum of the bottom readings (937) divided by their number (70).

Column Number	1	2	3	4	5	6
Position Number	**Reading x_i**	**Number of Readings**	**Product**	**$\mu - x_i$**	**$(\mu - x_i)^2$**	**Product**
			Col 1 x Col. 2			Col. 2 x Col. 5
2	10	5	50	-3.39	11.49	57.46
3	11	6	66	-2.39	5.71	34.27
4	12	7	84	-1.39	1.93	13.52
5	13	17	221	-0.39	0.15	2.59
6	14	19	266	0.61	0.37	7.07
7	15	10	150	1.61	2.59	25.92
8	16	2	32	2.61	6.81	13.62
9	17	4	68	3.61	13.03	52.13
Totals	-	70	937	-	-	206.58

To complete Table 5 it is first necessary to compute the value of μ using Formula 3.

$$\mu = \Sigma(x_i)/N \quad - \quad (3)$$

where

$\Sigma(x_i)$ = the sum of the readings -

N = the number of the readings -

i.e.: $\mu = 937/70 = 13.39$ -

and the standard deviation (± σ) is

$$\pm\sigma = \pm[\Sigma(x_i - x)^2/N]½ \quad - \quad (4)$$

where

σ = standard deviaton -

x_i = the reading number i -

$\overline{x}$ = the average reading -

N = the total number of reading -

For the example the standard deviation is:

$\pm\sigma = \pm[206.58/70]^{½} = \pm 1.72$ -

The standard deviation is a measure of how spread out the distribution is.

Two further statistical coefficients may be calculated but neither is strictly necessary. These are

1. the skew (ς),

2. Pearson's coefficient (ν).

The skew coefficient is a measure of the degree to which the bar graph is skewed to one side or the other and is calculated from the Formula:

$$\varsigma = 3(\mu - \mathbf{M})/\sigma \qquad (5)$$

where

ς	=	skew	-
M	=	median of the sample	-
μ	=	arithmetic mean value of the sample	-
σ	=	standard deviation	-

For the subject boat the latter value worked out as

$$\varsigma = \pm 3(13.39 - 13.00)/1.72 = +0.68 \quad -$$

Pearson's coefficient of variation is a measure of the intensity of the districbution of the measurements ans its calculated from the Formula:

$$\nu = \sigma/\mu \qquad (6)$$

where

ν	=	Pearson's coefficient	-
σ	=	standard deviation	-
μ	=	arithmetic mean value of the sample	-

This was calculated for the whole sample at

$$\nu = 1.72/13.39 = 0.13 \quad -$$

and that indicated a very narrow scatter of the measurements.

First check by the three sigma rule to see that all figures lifted lie within the range μ ± 3 σ *i.e.*, within the range

$$13.39 \pm 3 \times 1.72 = 8.23 \longrightarrow 18.55 \quad -$$

That being so the readings showing no rogue spots and the value of v being so low the analysis was based on the whole range of the readings. Here the marine surveyor should remember that all the readings are affected not only by the length of time that the boat has been out of the water at the time of the survey but also by the length of time she had previously been afloat. In the particular survey, the boat had been dry some sixteen days at the time of the inspection.

Analysis of Topside Readings

As stated, some 14 readings were taken on the dry topsides at the same time and they are also shown on Figure 3 to give a relative base to the readings taken on the under water parts of the boat. These topside readings had a range from 2 to 5 and an arithmetic mean value of 1.27 with a standard deviation of ± 1.00. The topside figures were calculated by the same method for those on the bottom.

General Comments

For the above calculations, which were carried out on a hand calculator, two decimal places are more than accurate enough. The figures, as might be expected, appeared, from the plot of the histogram given below, to have a probability density function that approximately followed the normal distribution.

The position of all of the points measured was randomly selected and the number of readings taken was based on a statistically significant percentage of the wetted surface area of the boat. Thesample/population ratio for both bottom and topside readings, however, must be considered to be fairly small but it can be shown that the following Formula gives a 95% confidence level and that, based upon the sample size taken, the mean value given above lies within an acceptable percentage of the whole population.

Wetness - Interpretation of the Analysis

Allowing for the ambient conditions as given above and the time the boat had been out of the water it is possible to show, using the first solution to Newton's differential equation, that the theoretical wetness reading should be of the order of:

$$W_{mnT} = 10 + 15e^{-t/100} \quad - \qquad (7)$$

where

W_{mnT}	=	theoretical wetness number	-
t	=	time out of the water	days
e	=	base of Naperian logarithms	-

For the subject boat out of the water for sixteen days the theoretical wetness number should, therefore, be of the order of:

$$W_{mnT} = 10 + 15 \times 2.7813^{-16/100}$$

$$= 10 + 15 \times 0.8521$$

$$= 22.78 \qquad -$$

In theory that figure should not be exceeded by a value given by the arithmetic mean of the bottom readings plus 1.96 times the standard deviation divided by the square root of the number of readings minus one half the skew after the mean value has been corrected to the standard conditions of ambient temperature 15°C and relative humidity of 50% as that suggests that the bottom had dried in accordance with Newton's differential equation and, additionally, was not retaining any breakdown products. The final corrected measured wetness number for the boat can then be calculated from:

$$W_{mnA} = \mu/[1 + (T_a - 15)/140][1 - (R_H - 50)/1000] + 1.96\sigma/N_R^{1/2} \pm \varsigma \qquad (8)$$

where

W_{mnA}	=	actual measured wetness number	-
T_a	=	ambient temperature	°C
R_H	=	percentage relative humidity	%
μ	=	arithmetic mean	-
σ	=	standard deviation	-
N_R	=	number of readings	-
ς	=	skew plus or minus	-

Thus, for the subject boat, the achieved wetness number was:

$$= 13.39/[1 + (18 - 15)/140][1 - (58 - 50)/1000] + 1.96 \times 1.72/70^{1/2} - 0.66/2$$

$$= 13.30 \qquad -$$

That has to be compared to the similarly corrected for statistical and ambient effects number NT for the topsides of:

$$N_T = 1.27/[1 + (18 - 15)/140][1 - (58 - 50)/1000] + 1.96 \times 1.00/14^{1/2} + 2.60$$

$$= 4.38 \qquad -$$

The ratio of these two figures being:

$$= 4.38/13.30 = 0.3293 \qquad -$$

A little thought will show that the higher this ratio the dryer will be the bottom compared to the dry topsides. Inspection of the given results will also show that the starboard topsides are slightly dryer than those to port although the reverse is true relative to the bottom readings. If this figure is low, say, lower than 0.25, that indicates that the bottom is considerably wetter than the topsides. Obviously the converse is equally true. The author considers that a value of between 0.325 and 0.55 is reasonable for a twenty year old boat. That means that the achieved ratio of 0.3293 would be considered to be reasonably satisfactory.

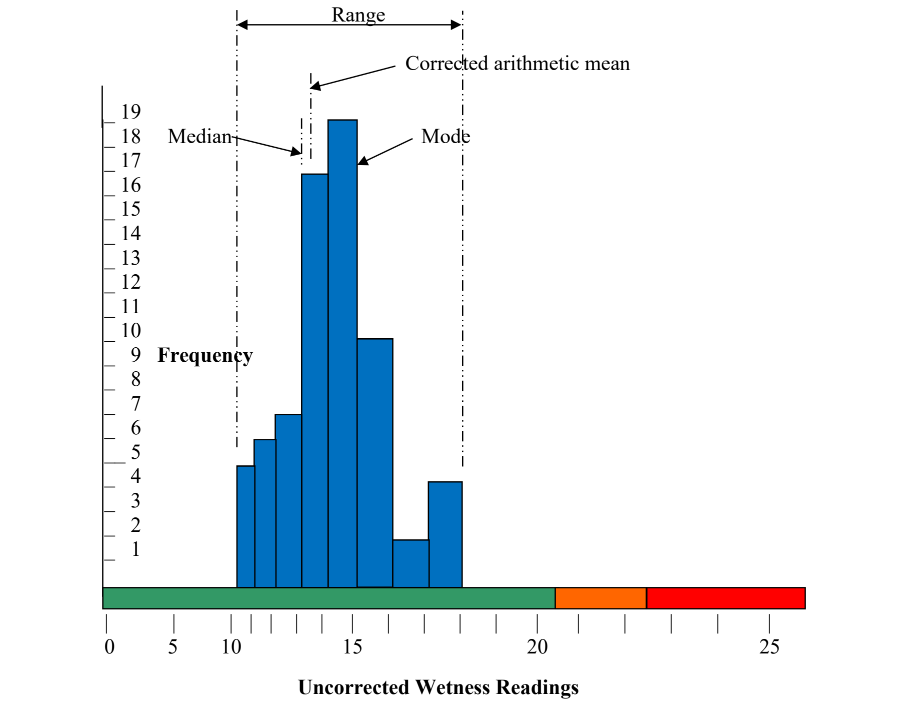


Figure 4 - Bar Chart for the Sovereign Machine Results

The question now arises as to what these wetness numbers actually mean. In other words, How wet was the hull in reality? For the Sovereign machine and from data in the author's possession taken from private experimental work carried out by himself, the arithmetic mean bottom reading given above would seem to indicate a moisture content of the laminate of the order of:

$$W.C. = 0.38 + \frac{W_{mn}^{1.19}}{34.72} \quad \% \qquad (9)$$

where

W.C.	=	the water content by weight of the laminate	%
W_{mnA}	=	actual measured wetness number	-

Thus, for the subject boat, the water content of the hull as a percentage by weight according to the Sovereign machine was, therefore, of the order of:

$$W.C. = 0.38 + \frac{13.30^{1.19}}{34.72}$$

$$= 1.006 \quad \%$$

The moisture content estimate was consistent with the information given by the resin manufacturer and did not give cause for concern. Again, it must be stressed that this statistical analysis does not allow the marine surveyor to predict whether or not the boat is about to suffer gel coat blistering and that in this case, as a precautionary measure, the author advised the Client that the boat probably contained about 1½% moisture by weight of the laminate and was probably in a reasonably satisfactory condition but he added the recommendation that the boat should be re-examined for moisture content before relaunching at the end of the lay-up period and, as stated above, that she should be slipped and the bottom examined at not more than one year intervals.

Giving a vessel with a wet bottom a coating of epoxy resin or paint is definitely not recommended. Experience will show that if such a vessel whose shell matrix is wet is given a coat of epoxy, then very quickly she will develop blisters.

SURVEYING TIPS

If the hull temperature is higher than the atmospheric dew point then the dew point can be ignored but if the opposite is true then the marine surveyor should check to see that the hull surface is clear of dew before applying the meter.

Readings outside the $\pm 3\sigma$ range should be specially investigated on the actual survey but may be ignored in the statistical calculations.

Negative skew values indicate that the actual wetness number is probably lower than that calculated while positive skew values indicate the opposite when it is **recommended** that additional readings be taken on the hull.

REFERENCE DOCUMENTS

The Professional Boatbuilder Number 23 page 42 Moisture Meters.
The Professional Boatbuilder Number 60 page 48 Moisture Meters Revisited.
The Professional Boatbuilder Number 69 page 31 More on Moisture Meters.
The Professional Boatbuilder Number 102 page 46 Reading the Meter.
The Professional Boatbuilder Number 104 page 128 Demolition Derby.

ABOUT THE AUTHOR

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Jeffrey N. Casciani-Wood is a Chartered Engineer with the additional title if European Engineer, a Fellow R.I.N.A., Hon. Fellow I.I.M.S. (Past President), Fellow S.C.M.S., and a Fellow of the Institute of Diagnostic Engineers and its current President. He is also on the IMO list of Marine Consultants (through IIMS). He holds an ONC, HNC and endorsements in naval architecture and the IIMS Diploma in Marine Surveying. To recognise his lifelong commitment and contribution to the marine surveying profession, Jeffrey was given a Lifetime Achievement Award, which was presented to him at the IIMS Conference Dinner in September 2015.

From January 1945 to October 1946 Jeffrey worked at the London Graving Dock Ltd on a pre-apprenticeship training course. Following that, from October 1946 to October 1951, with an indentured apprenticeship at the Orchard Dock as a shipwright. From October 1951 to 1957 he worked as a shipwright and made occasional trips to sea. From 1957 to 1964, Jeffrey worked at the Kort Propulsion Co Ltd (Green and Silley Weir Ltd) rising from junior draughtsman to general manager, designing propulsion equipment and attending new building bollard pull and sea trials. During the evening he taught naval architecture to ONC level at Poplar Technical College for six years during this time. From 1964 to 1973, Jeffrey worked for Messrs Hart Fenton and Co Ltd as superintendent of Greek tramp shipping on a world-wide basis. To date he has worked in over fifty countries, and from 1973 to 2005, acted as a freelance marine surveyor mainly on small craft till he retired on the death of his wife. For a period Jeffrey was on the London District Committee of SCMS and regularly reviewed applications for membership. He has acted as mentor to a number of junior surveyors and regularly attends meetings of the IIMS and I.Diag.E to keep up his CPD (continous professional development).

Jeffrey is the author of a number of books and papers published by IIMS.

eBook handy guides can be found at **https://bit.ly/3mRY8cq**

The use of moisture meters on small craft

The first thing to know about moisture meters is that they do not actually measure moisture. What they do measure is conductivity. The origins of the moisture meter lie in the building and construction industries and the original scale was based on the water content of brick and stone work. The scale has largely remained unchanged. There are a number of these machines available in the market and they were first introduced into the marine industry for checking how an frp hull had dried over time prior to rebuilding for osmosis treatment and for that they remain a useful tool. They are also used to check for moisture below a surface that looks dry.

Electrical moisture meters have an enormous advantage for the general survey as they are clean and non-destructive but they do have limitations and they do NOT quantitatively measure moisture on/in hull substrates. The majority record electrical resistance between two applied electrodes or capacitance and, more recently, some measure the reflection of radio frequency emissions from the meter.

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