HUMIDITY MEASUREMENT UNDERNEATH WET COMPOSITE WRAPPING FOR EARLY CORROSION DETECTION

by

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15098

FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

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Dr. Zainal Arif Burhanudin
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

MAY 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and the original work contained herein have not been undertaken or one by unspecified sources or persons.

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MUHAMMAD AZMIL BIN ADNAN

ABSTRACT

Recent development has allowed composite wrapping to be used to cure and protect the corroded pipeline from further corrosion. However, the integrity of the pipeline and the composite wrapping become a question mark since engineers were unable to determine the curing process progress. Hence, to meet the present day technologies, humidity sensor is proposed to be used in this project to monitor humidity underneath composite wrapping to determine the integrity of the pipeline and the composite wrapping. The project will be executed starting with the type of sensors analysis and sensors characterization; aim to increase the accuracies. Then move to the test jig development phase and lastly the test jigs testing with various condition. By the end of this project, the functionality of the humidity sensor underneath composite material will be determined. Hence, positive result will provide a platform for a company to use the sensors to evaluate the integrity of the pipeline underneath composite wrapping.

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Table of Content

List of Figures

List of Tables

Abbreviation

Abbv	**Definitions**
CCR	Center of Corrosion Research
IOSSB	Innovative Oilfield Services Sdn Bhd
LCR	Inductive, Capacitive and Resistive
RH	Relative Humidity
ROC	Readout Circuit
UTP	Universiti Teknologi PETRONAS

CHAPTER 1: INTRODUCTION

1.1 Background

Corrosion to pipeline and facilities will occur as long as elements like water, heat, and oxygen present around the pipeline. The fact that these elements exist naturally in the environment, hence, provide a constant threat of corrosion to the pipeline. Leaking that occurs at industrial pipeline, result from corrosion, will not only affect company's capital expenditure, but also the operational expenditure. The leaking lead to the need of the process production shutdown that uses specified pipeline will reduce the amount of production and eventually reduce the company's profit. .

Installing composite wrappings around the corroded pipeline will cure the corroded pipeline where corrosion and degradation has taken place. It will also protect the pipeline from the elements that are able to increase rate of corrosion. However, the integrity of the pipeline and the composite wrapping become question mark since the installation of the composite wrapping provide blind spot for engineers to analyze and determine whether the pipeline is currently in a healing stage or not.

Hence, monitoring water vapor by placing humidity sensor underneath composite wrapping is one of the ways to evaluate the integrity of the pipeline and the composite wrapping.

1.2 Problem Statement

The humidity sensor needs to be placed between the corroded pipeline and the composite wrapping. This can only be done during its installation that also requires the polymerization of the composite, changing state from wet and flexible to dry and stiff. However, the fact that the sensor is placed when the composite is wet questions the functionality of the sensors' absorption layer to absorb more water molecules.

1.3 Objectives and Scope of Study

1.3.1 Objectives

The objective of this project is to assemble a sensor and a system to measure humidity at atmospheric condition with the following features:

1. To investigate the functionality of the sensor underneath composite wrapping.
2. To test the sensor underneath composite wrapping in controlled humidity environment with atmospheric condition, RH variation and temperature variation.

1.3.2 Scope of Study

The project involves the understanding of relative humidity, humidity sensor working principle, and the assembly of readout circuit. However, measurement of relative humidity will only be done in lab scale measurement. In addition, the size of the metal and composite material is limited to 4×4 cm^2 use to wrap the corroded pipeline, which will be tested in atmospheric condition, controlled humidity, and temperature variation.

CHAPTER 2: LITERATURE REVIEW AND/OR THEORY

2.1 Humidity Sensors

Theoretically, humidity is define as the mass of vapor in surrounding air while RH is the amount of partial pressure vapor divided by the saturated vapor with similar amount of pressure and temperature[1].

The corrosion at pipeline results from the presence of oxygen, and enhance by elements such as humidity, temperature and amount of salt, needs to be cater and monitored continuously[2]. Data recorded in Relative Humidity for Meteorological Stations in Malaysia[3] shows that the range of humidity in Malaysia is between 60% and up to 98%. Hence, indicate the presence of threat of corrosion to the pipeline due to water vapor is really high since the highest RH available to prevent rusting occur on the surface of the pipeline is approximately 40%[4].

To prevent and protect the surface area exposed to the corrosion, oil and gas company, such as PETRONAS, usually will wrap the pipeline using composite material to protect and cure the pipeline from these elements[5]. However, wrapping the pipeline will eventually prevent engineers or operating personal to observe and evaluate corrosion due to a defect of composite wrapping. So, to determine the integrity of the composite wrapping, one of the ways is by monitoring one of the elements which catalyze the corrosion at the pipeline. Hence, this project will specifically observe the functionality of humidity sensor used to measure RH underneath composite wrapping.

Table 1: Elements with respect to its variables

Variables	**Elements**
Manipulated Variable	Relative Humidity
Responding Variable	Electrical Impedance / Dielectric Constant
Disturbance	Temperature

There are 3 types of humidity sensors; resistive humidity sensor, capacitive humidity sensor, and thermal humidity sensor. However, in this experiment, only 2 types of electrical humidity sensors is going to be evaluated; resistive type and capacitive type humidity sensor[1]. This is because temperature is the main disturbance to the measurement and hence, will affect the integrity of the value provided by thermal humidity sensor.

Table 2: Advantages and disadvantages of resistive humidity sensor and capacitive humidity sensor[6]

Resistive Humidity Sensor	**Capacitive Humidity Sensor**
Advantages - Field replaceable where interchangeability only within ±2% of RH. - Small size, low cost, and long term stability.	**Advantages** - Minimal long-term drift and hysteresis. - Able to function at high temperature with wide RH range. - Full recovery from condensation
Disadvantages - Tendency to shift values when exposed to condensation. - Significant temperature dependencies.	**Disadvantages** - Limited by the distance of the sensing element (<10 ft.). - Direct field interchangeability (more than ±2% of RH) unless laser trimmed.

In this project, capacitive humidity sensor will be used throughout the project to calculate and analyze RH underneath composite material. By having better quality in terms of reliability, hysteresis, and lower impact from temperature disturbance [7], W. C. Lee et al[8] states that it has higher sensitivity to RH compared to resistive humidity sensor.

Table 3: Resistive vs capacitive humidity sensor [9]

Resistive Humidity Sensor	**Capacitive Humidity Sensor**
Use electrical impedance of hygroscopic medium : conductive polymer and salt	Use dielectric constant to measure RH : polyimide and air
Medium sensitivity of RH	Higher sensitivity of RH
Higher impact due to temperature	Lower impact due to temperature

Technically, both types of humidity sensor use almost the same components; conductive polymer and 2 electrodes. The main difference is the design itself. For capacitive humidity sensor, the substrate is deposited between two layers of electrodes, allowing the substrate to act as a dielectric capacitance. The surrounding water vapor will be absorbed by the polymer until the water vapor content is equilibrium to the surrounding water vapor. Hence, increases the dielectric constant of the sensor[7].

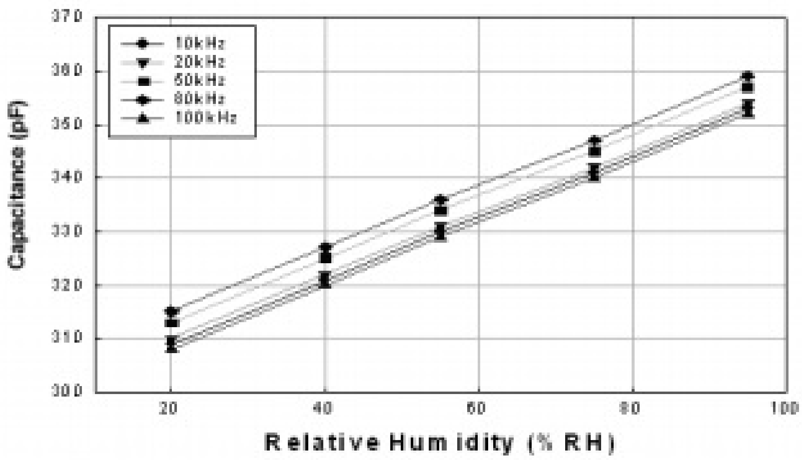


Fig. 1. Capacitance vs RH graph for HCH-1000 series[10]

In comparison, resistive humidity sensor uses 2 electrodes design in the shape of the comb, separated by polymeric film. Similar to the substrate use by capacitive humidity sensor, these polymeric films absorb surrounding water vapor, result in dissociation of ionic functional group, hence, result in an increase in electrical conductivity of the film.

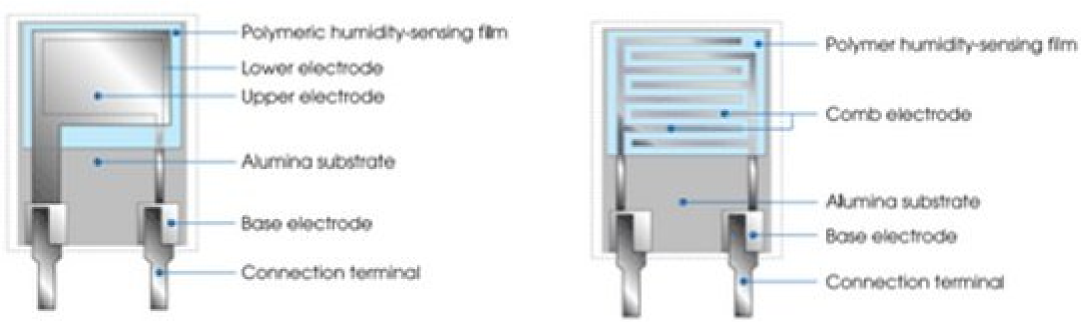


Fig. 2. Basic structure of capacitive and resistive humidity sensor[9]

Capacitance is a term used to describe charge capacity stored between two plates of electrodes. Capacitive humidity sensors use polyimide and air gap as a material used to detect moisture concentration[10]. However, RH is measured through polyimide as according to U. Kang & K. D. Wise[11], "the dielectric constant of air changes by only 1.4 ppm/%RH while that of polyimide changes by 3330 ppm/%RH". Dielectric constant inside capacitor increase proportionally to the increase of humidity absorption at polymer[12]. Hence, result in in the increase in the amount of capacitance of the sensor. Because of this, capacitors are able to act as a tool sensor or components that can vary with respect to the change of surrounding RH.

2.2 RH Readout Circuit

In order to directly obtain Relative Humidity (RH) from the sensor, Readout Circuit (ROC) is needed. Several types of method have been introduced, including, resonance method, oscillation methods, charge and discharge method, and many more[13]. Even though A. Hassanzadeh & R. G. Lindquist[13] indicate that charge and discharge method is more accurate, the method needs to have 2 humidity sensors to identify capacitance change.

In this project, an oscillation method is used as a ROC for capacitive humidity sensor. It produces frequency which varies due to the change of capacitance. Figure below shows the examples of LC Meter ROC.

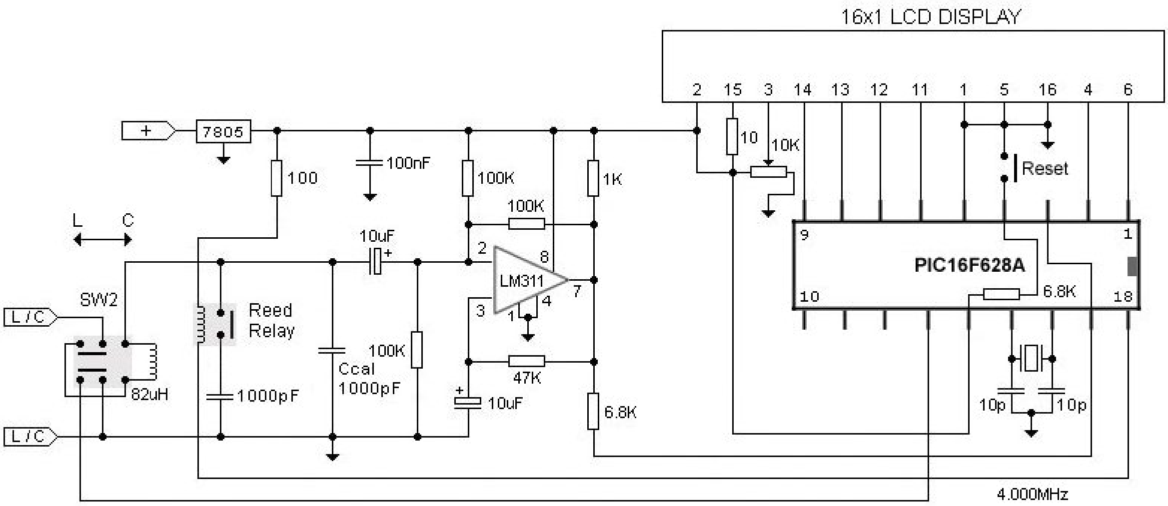


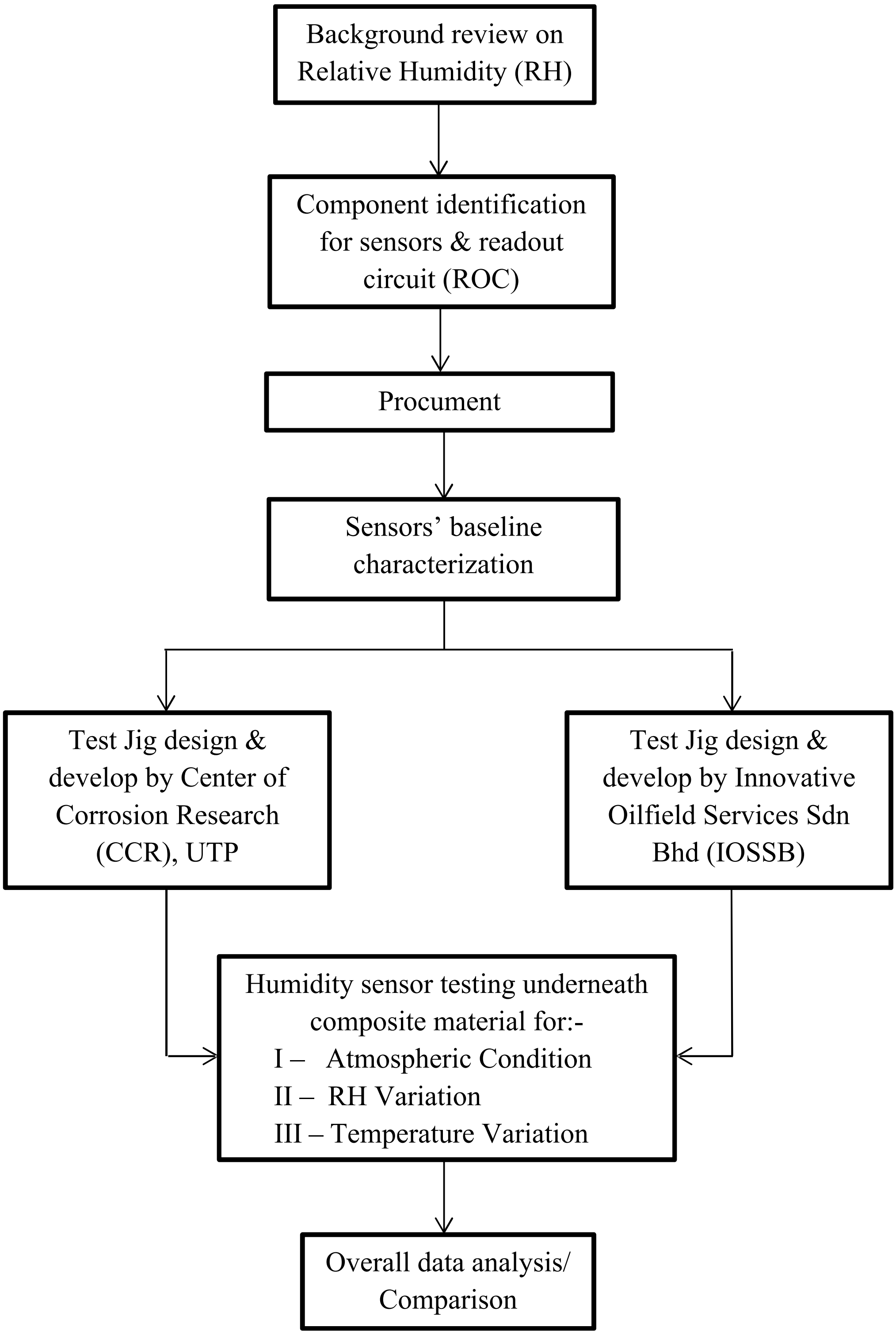
Fig. 3. Readout Circuit[14]

This LC circuit is able to read capacitor and inductor by producing certain output level of frequency at LM311 oscillator. The output voltage of LM311 will have saturation voltage of about approximately 5V since the input provided is only 5V. However, since the objective of providing 5V to LM311 is only to produce signal oscillation, the saturation voltage will only act as a minor disturbance and will not largely affect the signal frequency. Manually, the frequency can be calculated using the normal inductance and capacitance formula. Hence, several changes in the circuit design will occur to suit the humidity sensor used in the experiment.

In addition, PIC and LCD Display is assembled together with frequency-generated circuit to become ROC in order to display the value of capacitor or even inductor to the LCD Display[15]. PIC programming will read and convert the frequencies obtain with respect to the humidity sensor connected at the probe of the circuit and change it to Relative Humidity (RH) value. LCD will then do the task to display the value provided by PIC.

CHAPTER 3: METHODOLOGY/PROJECT WORK

3.1 Flow Chart



Strategizing project planning and methodology is necessary in order to complete the project within the period of time. Flow chart 3.1 shows the overall methodology until project completion from FYP 1 until FYP 2. For this project, relative humidity (RH) is the primary element that needs to be study and understand first since it is the main parameter that will be evaluate and analyze throughout the project execution. Hence, understanding of relationship and the effect of Relative Humidity (RH) to the corroded pipeline is crucial in order to finalize and conclude the data obtain.

To commence the project, identifying the type of sensors and readout circuit to be use in the project will create a pathway to recognize which type of electronic device is better to be use throughout the project and will be purchase, design, install and assemble. Humidity sensors and instrument devices were not only evaluated based on the price of the components to be purchase, but also in terms of the features of the products, including capacitance range, response time, operating temperature, and others. Only one type of humidity sensor (capacitive, resistive, or thermal) will be purchase and used throughout the project. In addition, several electrical instruments for LCR meter kit and digital hygrometer will also be evaluated to be include in procument part to strengthen and further improve data validation.

Standard Operating Procedure (SOP) for LCR meter kit need to be strictly followed in order to obtain precise value provided by sensor. Several variables, including manipulated, responding and disturbance are also need to be identified before the execution of the project.

Humidity sensor testing and characterization in Nitrogen Box with a presence of digital hygrometer to determine the actual baseline of every humidity sensor insists the project to take another step in identifying the availability of having Readout Circuit (ROC) for the project or not. The assembly of the ROC which intended to show the value of RH directly from the sensors depends on the characterization result of the humidity sensors. If the characterization data analysis provides positive result, ROC design and assemblies will be done simultaneously with the design and creation of test jig. The study of ROC is required to determine and evaluate the suitability of the type of sensor and also its parameters.

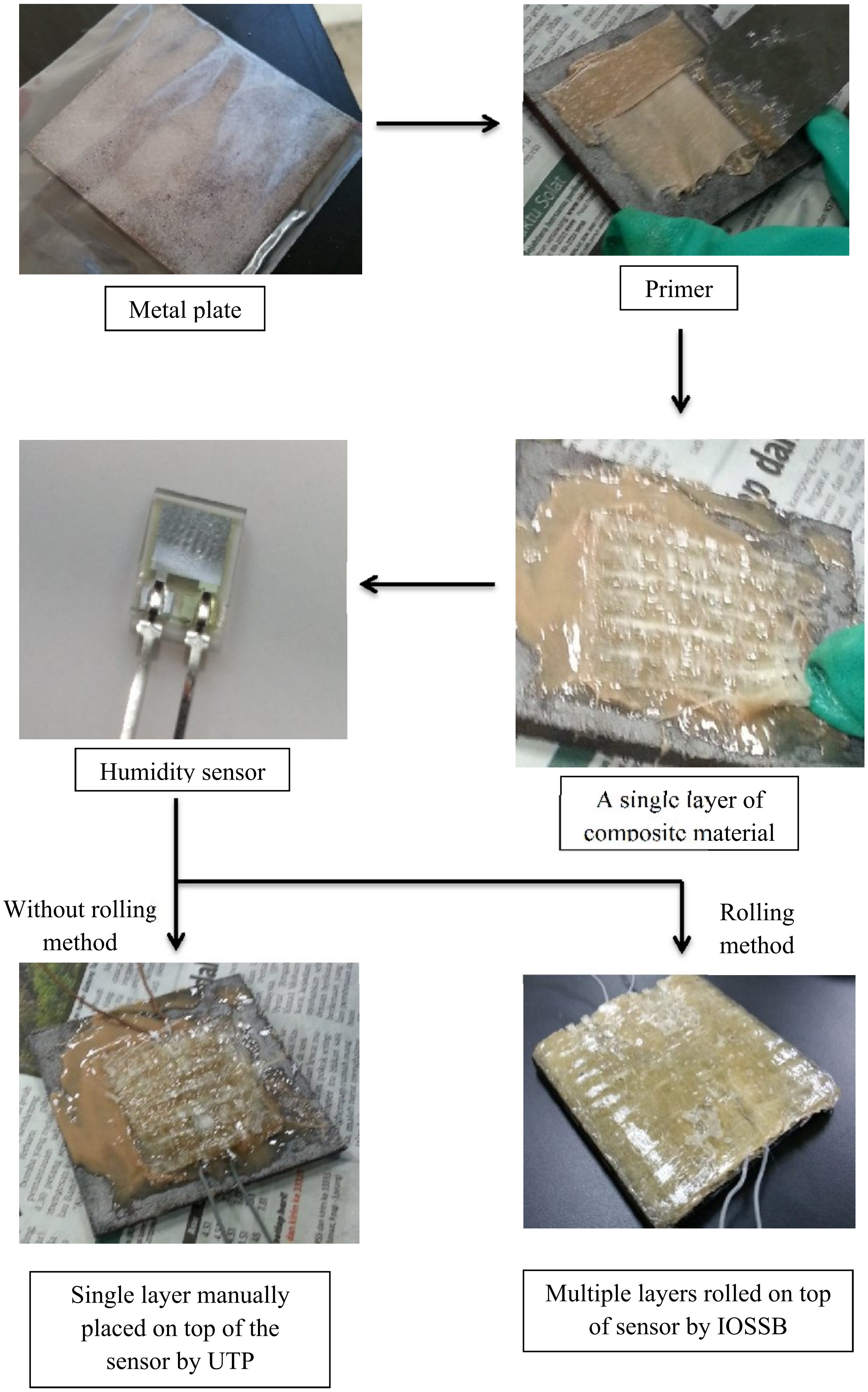


Fig. 4. Test jig design & development for UTP & IOSSB

Metal plate, primer liquid, several layers of small sized composite material and humidity sensors required to develop a test jig. For test jig designed by UTP, a single layer of small sized composite material will be attached to the corroded metal plate using high viscosity liquid called primer. Then, the humidity sensor will be placed on top of the first layer of composite material. Then, a single composite material will stick on top of the sensors just to cover the sensor from ambient water vapor. For the test jig designed by IOSSB, the final step is the only different step compared to UTP design.

Eventhough the project was said to be in a lab scale measurement, IOSSB will use the technique they have implemented to all their client companies during the installation of composite material wrapped around the corroded pipeline. Several layers of composite material was placed and rolled on top of the humidity sensors. The technique will provide solid layers of composite material to the top of the test jig. Hence, since this is the actual technique to be used during the installation of composite wrappings, the sensors functionality will be mainly evaluated throughout the IOSSB design.

So, the purpose of installing the sensor underneath the composite material is to determine whether the sensor will manage to provide amount of RH under wet composite material. If the sensors are able to determine the amount of RH, it will be used to identify whether the humidity underneath composite material is similar, lower or even vice versa to the surrounding humidity level.

Under composite material, there will be 3 type of testing variation to be executed; atmospheric environment condition, RH variation and temperature variation. Execute 3 types of testing to the system is necessary in order to validate Relative Humidity data obtain from the humidity sensor placed in various conditions. This will be the last part of the final year project to develop and analyze the strength of the composite material to withstand and prevent the elements from affecting metal pipeline.

3.2 Gantt Chart and Milestone Planning

Final Year Project I															
No	Activities	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Title Selection	■	■												
2	Preliminary Research & Literature Review		■	■	■	■									
2	Component Identification & Evaluation				■	■	■								
3	Procument						■	■	■	■	■	■			
4	Sensors Preliminary Testing									■	■				
5	HCH-1000 Sensor Characterization											■	■		
6	MK-33 Sensor Characterization												■		
7	UTP test jig design analysis & development												■	■	■

Final Year Project II															
No	Activities	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	UTP test jig testing in atmospheric condition	■	■	■	■	■	■	■	■						
2	Test jig design & development by IOSSB						■	■	■	■					
2	Test and validate under composite wrapping (atmospheric condition)									■	■	■	■	■	
3	Test and validate under composite wrapping (RH Variation)									■	■				
4	Test and validate under composite wrapping (temperature varation)												■	■	
5	Final Report & Technical Paper Report												■	■	■

Fig. 5. FYP I and FYP II Gantt Chart

<u>Final Year I Project Milestone</u>

Title selection	: Week 2
Preliminary research & literature review	: Week 5
Component Identification	: Week 5
Sensors Preliminary Testing	: Week 10
Procument	: Week 11
HCH-1000 Sensor Characterization	: Week 12
MK-33 Sensor Characterization	: Week 12
UTP test jig design analysis & development	: Week 14

Final Year II Project Milestone

UTP test jig testing (atmospheric condition)	: Week 7
IOSSB test jig development	: Week 9
IOSSB test jig testing (RH variation)	: Week 10
IOSSB test jig testing (temperature variation)	: Week 13
IOSSB test jig testing (atmospheric condition)	: Week 13

The combination period of FYP 1 and FYP 2 is approximately 8 months starting from January 2014 until September 2014. In this project, FYP 1 will focus more on understanding the fundamental of the case study, such as variables to be measured, disturbance variable, manipulated variable, the preliminary testing and sensors characterization and as well as the test jig design analysis. The first part also includes the identification of the type of humidity sensor to be use throughout this project.

During the FYP 2 period, the process to design and develop test jig design will be executed for both UTP and IOSSB after the completion of the characterization of humidity sensors. Similar to FYP 1, several challenges and obstruction obtain during the testing in FYP 1 requires changes in project development's methodology, specifically for FYP 2. Then, after the actual baseline for all sensors available have been analyzed, the project progress will then proceed to the test jig set up by Center of Corrosion Research (CCR), UTP and by Innovative Oilfield Services Company (IOSSB) at their premise.

The test jig design by UTP will be first tested and evaluated to determine the functionality of the sensors installed underneath composite material, using UTP technique. This will provide a platform and references for the main testing, executed using test jigs design by IOSSB.

After IOSSB design and develop the test jig and sent it back to UTP, main experiment involving atmospheric condition, Relative Humidity (RH) and temperature variation was done to the test jigs. This is basically to identify and determine whether the humidity sensors are able to withstand the condition and pressure underneath composite wrappings, including the quality and integrity of the composite material which is to protect the metal pipeline from external elements that increases the rate of corrosion. However, in this project, the sensor will only measure one of the elements that increase the rate of corrosion to the pipeline, which is the level of RH underneath composite material.

Overall, several changes on Gantt chart need to be done throughout the project execution since the development of test jig as well as preparation to use weathering chamber consume the project period.

CHAPTER 4: Results and Discussion

Several humidity sensor testing was conducted throughout the FYP 1 period. Before the actual testing of humidity sensor is done, preliminary testing is necessary in order to familiarize with the procedure to measure responding variables (capacitance) and to identify the accuracy of the humidity sensor provided by the manufacturer. In addition, the early testing will also determine the actual process and methodology used throughout this project.

Fig. 6. Portable LCR Meter Kit and Digital Hygrometer

Instead of directly provide the actual value of RH, capacitive humidity sensors will only provide the amount of capacitance with respect to the change of surrounding RH. Hence, LCR meter kit needs to be used throughout the data collection to measure the amount of capacitance to determine the amount of RH for that specific area.

The LCR meter needs to be calibrated and set up accordingly before the start of the experiments. In addition, the capacitive humidity sensor is also need to be discharge to remove electrical charge balance stored in the capacitance. The capacitance measured and hygrometer value obtain was taken 5 times for every iteration during sensors characterization and during data collection in the test jigs.

4.1 Humidity Sensors Preliminary Testing

4.1.1 Test under Controlled Humidity Environment

The testing was executed in Center of Corrosion Research (CCR) in UTP. In this experiment, two similar type of humidity sensor (HCH-1000), purchased from Honeywell is used to measure RH inside the controlled relative humidity storage box (desiccator).

The purpose of this experiment is to identify the accuracy of the sensor by comparing the value obtain using LCR meter kit with the value obtain from the analog-type relative humidity (RH) display at storage box. The data obtain from the experiment is measured and recorded in the table below.

Table 4: Humidity sensor tested under controlled humidity environment

No of Meas.	**Humidity Sensor 1**			**Humidity Sensor 2**		
	Cap. Value	**RH based on datasheet**	**RH display at the box**	**Cap. Value**	**RH based on datasheet**	**RH display at the box**
1	316.0 pF	30%	43%	308.5 pF	21%	45%
2	318.4 pF	36%	50%	323.6 pF	45%	50%
3	320.2 pF	40%	54%	325.6 pF	47%	54%
	318.2 pF	**36.7%**	**49%**	**319.2 pF**	**37.7%**	**49.7%**

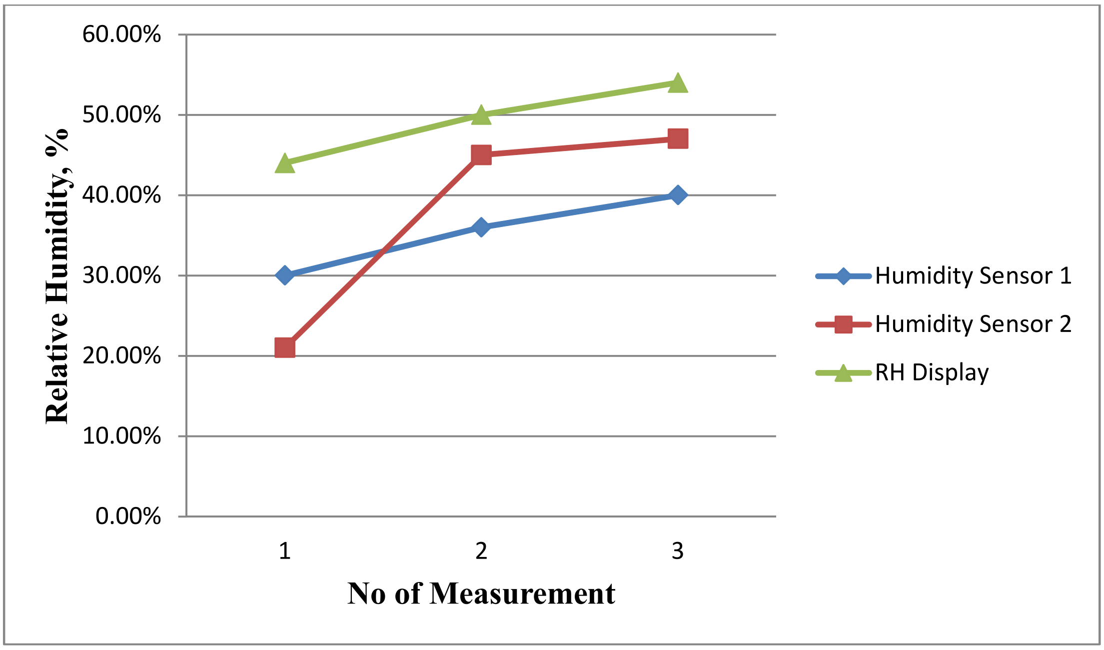


Fig .7. Graph of Humidity Sensor Testing in controlled RH Environment

Fig. 8. Desiccator used to test humidity sensor for controlled humidity environment

The output result provided by both sensors shows that the amount of capacitance with respect to RH were not only differ from one another, but also between the data from the sensors as well as RH analog display. However, the increment pattern in the graph is similar between the sensors as well as the RH analog display. The difference might be due to the wires installed at the leg of the sensors.

In addition, the analog display at the storage box has low response time compare to humidity sensor and LCR meter, which maybe one of the reason of the difference occur between the sensors data and the analog display data. In addition, the date of this analog hygrometer being calibrated also being questioned in this experiment. Hence, apart from direct humidity sensor testing, installation of wiring to the leg of the sensors needs to be tested in order to determine the effect of the wires connected to the leg of the sensors.

4.1.2 Humidity Sensor Testing in Presence of Digital Hygrometer

Table 5: Humidity sensor tested in a presence of digital hygrometer

No of Meas.	Humidity Sensor 1			Humidity Sensor 2		
	Cap. Value	RH based on datasheet	RH display at hygrometer	Cap. Value	RH based on datasheet	RH display at hygrometer
1	337.0 pF	68%	61.8%	331.0 pF	57%	61.8%
2	323.2 pF	45%	62.7%	318.0 pF	37%	62.7%
3	323.4 pF	45%	62.5%	320.6 pF	40%	62.5%
4	325.5pF	48%	67.6%	323.0pF	45%	67.1%
5	322.1pF	44%	66.6%	324.0pF	47%	67.4%
6	329.9pF	57%	67.1%	337.5pF	68%	67.8%
	326.9 pF	**51.17%**	**64.72%**	**325.7 pF**	**49%**	**64.88%**

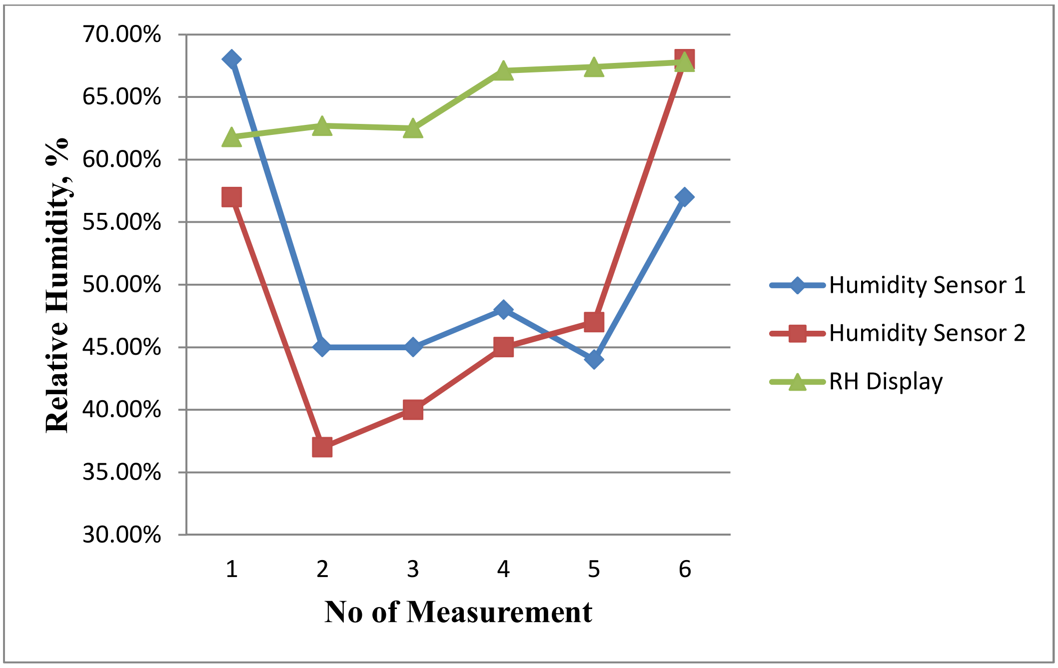


Fig. 9. Graph of RH data for humidity sensor tested in a presence of digital hygrometer

This experiment was done inside PPCS lab in a presence of fixed digital hygrometer to confirm, validate and add the data recorded in the first experiment without wires installed at the leg of the sensor.

However, eventhough without the use of wires, difference in data obtains between humidity sensor and the hygrometer still exists, between the sensors itself, and also with digital hygrometer. Random testing to all sensors purchase is also done and also shows different amount of capacitance with respect to the RH. Hence, before the installation of humidity sensors underneath composite material, sensors characterization is necessary to be done and executed in the project.

The difference of value obtains between humidity sensor used and hygrometer exists in this experiment maybe result from inaccurate Standard Operating Procedure (SOP). The humidity sensor that was directly measured once it has been discharge and the data directly taken once the sensor was connected to LCR Meter, in which the capacitance inside the humidity sensor is not stabilize yet. Using typical high precision instruments to measure very small capacitance may require long period of time for the instrument to stabilize to avoid transients' data.

4.1.3 Humidity Sensor Testing With and Without Wiring Installed at the Legs of the Sensor

The data in Table 6 and Fig. 10 shows the difference of RH value provided by the humidity sensor when connected with and without wiring. The difference of value obtain are due to the resistance exists inside the wires.

Table 6: Humidity sensor tested with and without wiring connected between LCR meter and the sensor

No of Meas.	**W/o wiring**		**With wiring**	
	Cap. Value	**RH based on datasheet**	**Cap. Value**	**RH based on datasheet**
1	332.4 pF	60%	340.8 pF	75%
2	329.0 pF	55%	337.5 pF	69%
3	330.6 pF	57%	338.5 pF	70%
	330.7 pF	**57.3%**	**338.9 pF**	**71.3%**

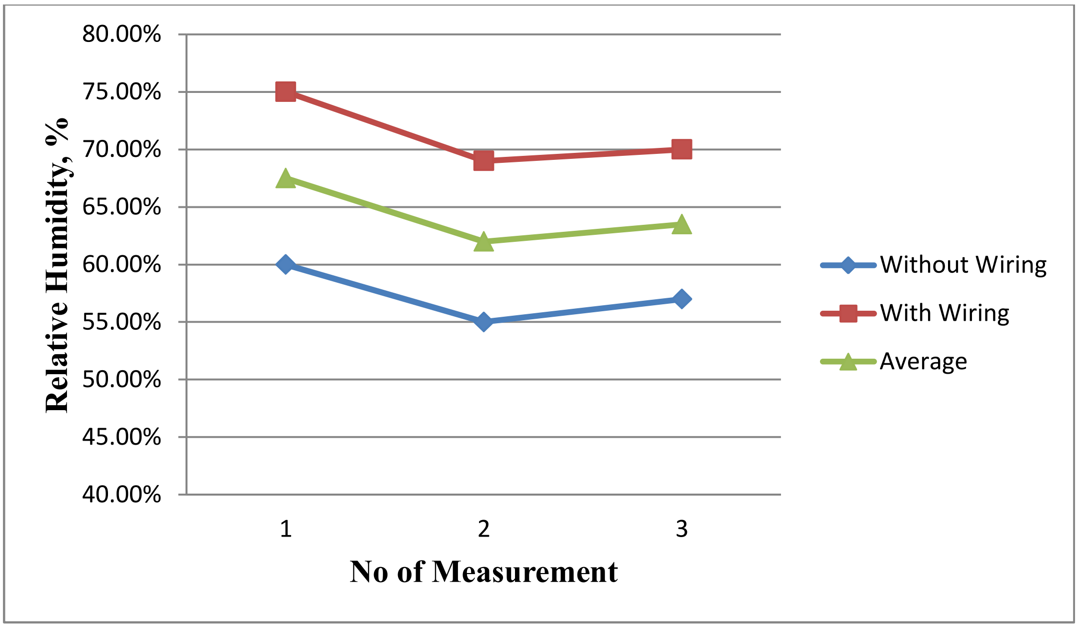


Fig. 10. Graph of environment testing with & without wiring connected between LCR meter and the sensor

Eventhough the effect of the wires can be said to be neglected since the length of the wires installed in every each one of the sensors were shorter than 10 feet and also because the experiment only use 10kHz frequency, due to the fact that the range of capacitive humidity sensor is within Pico farad (pF) value, small effect from others will still actually affect the amount of RH. Hence, the wires will still change the amount of RH and reduces the accuracy and the precision for the sensors underneath composite wrappings.

Throughout the experiment of measuring humidity sensor during preliminary testing, we found that every sensor provide different amount of capacitance at similar Relative Humidity (RH) provided by digital hygrometer. Hence, create difficulties to accurately measure the amount of RH as well as Readout Circuit ((ROC) development and assembly. Based on all these reasons, procedure to measure humidity sensor was improvise as the sensors characterization was done to obtain more accurate data and to decide whether to proceed with ROC development or not.

4.2 Humidity Sensor Characterization

Several sensors were tested during preliminary testing to determine the precision and accuracy of the sensors. The result shows that every each sensor provide different amount of capacitance at specific RH. Hence, sensors' characterization is necessary to be done to every each humidity sensors to identify and reduce offset and sensitivity error for all sensors. The characterization will result in a development of new baseline for each sensor.

4.2.1 HCH-1000 Data Characterization

Throughout the experiment, by using nitrogen box in CCR to manually manipulate RH while maintaining the disturbance, which is temperature, the baseline for four HCH-1000 capacitive humidity sensors is measured and analyzed. The data obtain was recorded in the Table 7 and Fig. 11.

Table 7: HCH-1000 humidity sensor characterization data

No	Average Cap. Value, , pF	Average Sensor RH, %	Average Environment RH, %	Max Cap. RH, %	Min Cap. RH, %	Standard Deviation,	Offset Error, %
Humidity Sensor 1 Characterization							
1	311.02pF	23.83%	32.38%	45.86%	7.35%	13.87	-8.552%
2	327.24pF	48.93%	53.56%	51.41%	46.36%	2.22	-4.63%
3	339.02pF	71.54%	70.58%	74%	69.7%	1.80	0.96%
4	342.2pF	76.76%	73.34%	80.4%	69.7%	4.11	3.418%
5	341.7pF	76.14%	77.66%	82.04%	73.65%	3.38	-1.52%
Humidity Sensor 2 Characterization							
1	302.48pF	12.02%	31.38%	31.43%	0%	11.72	-19.36%
2	325.52pF	48.02%	54.4%	50.1%	45.04%	2.06	-6.38%
3	332.8 pF	60.13%	70.72%	62%	57.78%	1.73	-10.59%
4	341.16pF	75.09%	73.7%	77%	69.89%	2.95	1.39%
5	337.78pF	69.36%	77.76%	70.22%	67.64%	0.99	-8.40%
Humidity Sensor 3 Characterization							
1	308.14pF	19.20%	33.54%	34.73%	13.13%	8.92	-14.34%
2	328.78pF	52.85%	55.1%	55.07%	51.41%	1.46	-2.25%
3	343.94pF	79.50%	70.96%	86.67%	72.93%	5.25	8.53%
4	348.74pF	88.01%	73.9%	89.7%	86.9%	1.17	14.11%
5	350.46pF	90.59%	77.56%	95.39%	85.86%	3.48	13.03%

Humidity Sensor 4 Characterization							
1	307.92pF	18.77%	31.86%	22.2%	15.1%	3.01	-13.09%
2	329.14pF	53.45%	54.94%	55.07%	51.24%	1.65	-1.49%
3	344.42pF	80.58%	71.12%	82.55%	77.69%	2.38	9.46%
4	348.74pF	88.01%	73.9%	89.7%	86.9%	1.17	14.11%
5	350.46pF	90.59%	77.56%	95.39%	85.86%	3.48	13.03%

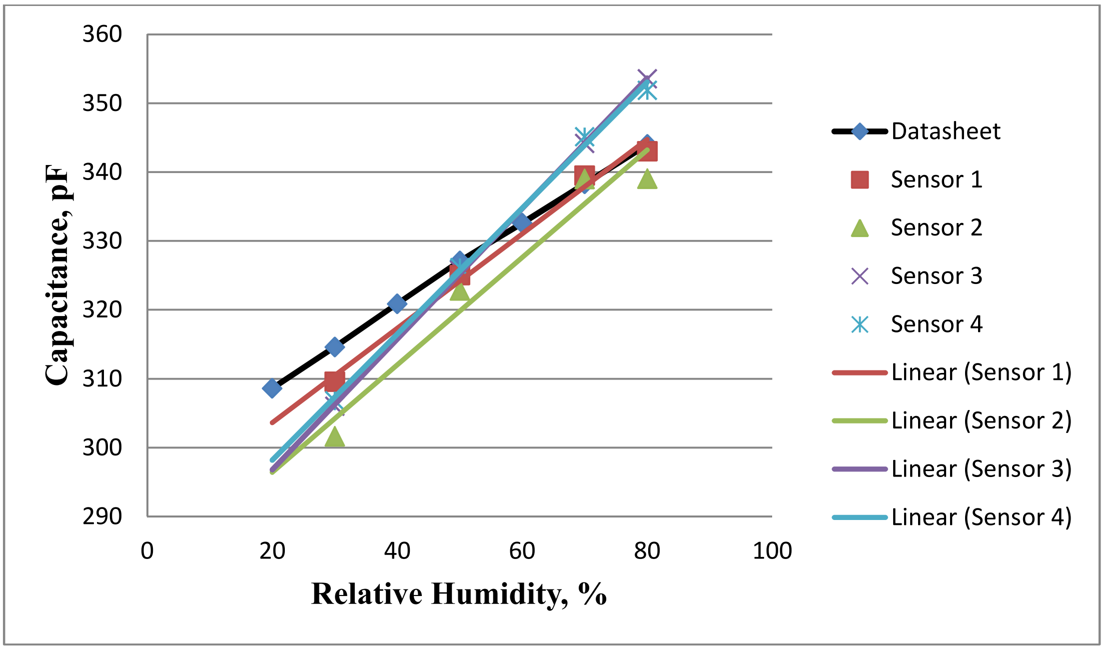


Fig. 11. Graph of capacitance vs RH for HCH-1000 humidity sensor

Fig. 12. Nitrogen box in CCR used to characterize humidity sensor

By referring to the baseline obtain in Fig. 11, we found that each one of the sensor has different baseline. This shows that every sensor has offset error and sensitivity error, which makes them not accurately follow the baseline provided by the vendor. Only Sensor 3 and Sensor 4 are having almost similar baseline with each other.

The level of precision or the consistency of HCH-1000 capacitive humidity sensor can be said as low-medium, meaning that the value of standard deviation for every experiment is above 1. This is probably due to the effect of wires soldered at the legs of the sensors and also due to the fluctuation of controlled RH environment during data collection. However, considering the sensor is very sensitive to the surrounding RH, the fluctuation shown in the data are considerable.

4.2.2 MK-33 Data Characterization

Similar to HCH-1000 sensor, MK-33 humidity sensor also undergo characterization process inside Nitrogen Box in CCR to obtain the baseline for all four sensors available for the experiment. The data was recorded in Table 8 and analyzed as shown in Fig. 13 below.

Table 8: MK-33 humidity sensor characterization data

No	Average Cap. Value, , pF	Average Sensor RH, %	Average Environment RH, %	Max Cap. RH, %	Min Cap. RH, %	Standard Deviation,	Offset Error, %
Humidity Sensor 5 Characterization							
1	314.62pF	61.04%	29.42%	67.63%	53.5%	6.75	31.62%
2	317.26pF	67.08%	39.02%	70.3%	61.5%	3.31	28.06%
3	322.64pF	79.11%	48.12%	81.5%	76.4%	1.93	30.99%
4	323.34pF	80.57%	53.58%	82.55%	78.5%	1.73	26.99%
5	325.42pF	85.2%	61.02%	91%	81.28%	4.46	24.18%
6	335.14pF	>100%	76.98%	>100%	>100%	-	-
Humidity Sensor 6 Characterization							
1	309.3pF	49.34%	29.58%	55.15%	43.05%	5.12	19.76%
2	310.34pF	51.71%	38.72%	57%	48%	3.57	12.99%
3	317.52pF	67.86%	47.66%	70.75%	65.8%	1.86	20.2%
4	320.88pF	75.51%	53.64%	76.5%	74.25%	0.98	21.87%
5	318.84pF	70.5%	60.58%	74.75%	68.35%	2.66	9.92%
6	332.16pF	>100%	76.78%	>100%	98%	-	-

Humidity Sensor 7 Characterization							
1	320.94pF	75.37%	29.14%	77.75%	69.55%	3.36	46.23%
2	327.46pF	89.91%	47.82%	91%	87.55%	1.37	42.09%
3	341.94pF	>100%	77.06%	>100%	>100%	-	-
Humidity Sensor 8 Characterization							
1	320.66pF	74.74%	29.28%	81.4%	69.45%	5.06	45.46%
2	325.66pF	86.04%	47.94%	89%	83.85%	2.00	38.1
3	341.98pF	>100%	76.98%	>100%	>100%	-	-

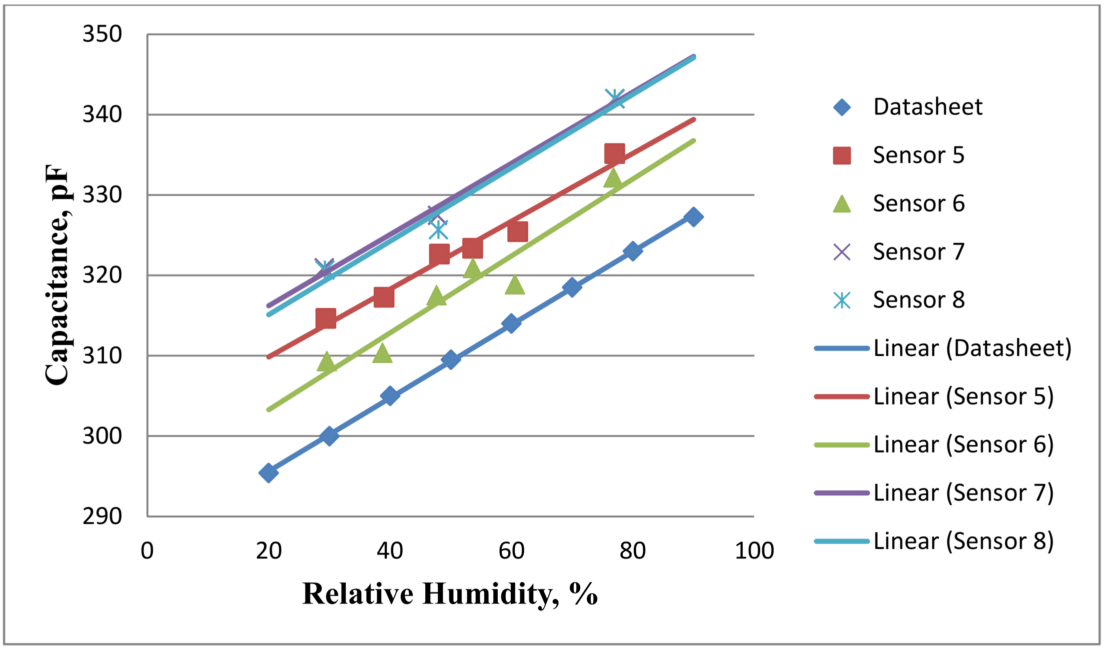


Fig. 13. Graph of capacitance vs RH for MK-33 humidity sensor characterization

MK-33 humidity sensor was intentionally used as a backup in case if HCH-1000 is malfunction and unable to be installed underneath composite wrapping. However, after the characterization is done, the baselines data obtain for all 4 MK-33 sensors are totally different compared to the baseline provided in the datasheet, similar to the problem faced on sensor HCH-1000. Only two sensors, Sensor 5 and Sensor 6 have quite similar characterization. The data collected from characterization shows that every sensor have high amount of offset error and have slight sensitivity error, compared to the baseline provided in the datasheet.

Furthermore, MK-33 has medium-low precision and data consistency. Most of the value obtain during data analysis for standard deviation in Table 8 shows that the value is higher than 1. This may result from the external effect, such as the length of wires attached to the leg of the sensors, and also RH fluctuation during the experiment. However, MK-33 precision is much better compared to HCH-1000 sensor with much lower amount of standard deviation calculated.

Overall, the difference in values of capacitance between all humidity sensors, HCH-1000 and MK-33 obtain during sensors' characterization provides difficulties to develop ROC for the project since the baseline value for every sensor is different. Hence, the development of ROC was cancelled due to this matter, and also the extension of sensor characterization and testing variation. In addition, eventhough developing ROC can provide direct RH readings from the value of capacitance, it will only create more error and inaccuracies to the user. Hence, ROC is not suitable to assemble and develop for the purpose of analyzing the amount of capacitive humidity sensors.

4.3 Humidity Sensor Testing underneath Composite Material

The testing of humidity sensor underneath wet composite material used to wrap the pipeline is the main experiment for the final year project where the humidity sensors will be measured and analyze to determine the functionality of the sensors. 3 test jigs, one developed by CCR from UTP and another two developed by IOSSB, were set up to measure and analyze the capacitive humidity sensors installed.

4.3.1 Humidity Sensor Testing underneath Composite Material design by CCR, UTP

Table 9: Humidity sensor testing underneath composite material at environment condition

Week	Average Cap. Value, , pF	Average Sensor RH, %	Average Environment RH, %	Max Cap. RH, %	Min Cap. RH, %	Standard Deviation,
Humidity Sensor 1						
1	308.63 pF	21.33%	71.33%	25%	17%	4.04
2	322.6 pF	42%	50.67%	49%	38%	6.08
3	321.52 pF	40.8%	57.2%	42%	40%	0.84
4	322.28 pF	42.2%	66.72%	43%	41%	0.84
5	324.1 pF	45.22%	54.52%	45.38%	44.9%	0.20
6	324.12 pF	45.23%	54.64%	46.68%	43%	1.35
7	324.68 pF	46.2%	48.7%	47.04%	45.54%	0.57
8	324.5 pF	46.02%	49.76%	46.36%	45.5%	0.33
Humidity Sensor 2						
1	320.4 pF	40.33%	71.33%	44%	37%	3.51
2	330 pF	53.42%	50.67%	53.58%	53.1%	0.28
3	330.04 pF	53.48%	57.2%	53.74%	53.26%	0.23
4	331.84 pF	57.93%	66.72%	58.35%	57.71%	0.24
5	332.2 pF	58.76%	54.52%	61.04%	58.03%	1.31
6	333.26 pF	60.95%	56.64%	68%	58.03%	4.27
7	330.9 pF	56.17%	48.76%	57.37%	53.9%	1.38
8	331.12 pF	56.77%	49.94%	57.08%	56.57%	0.22

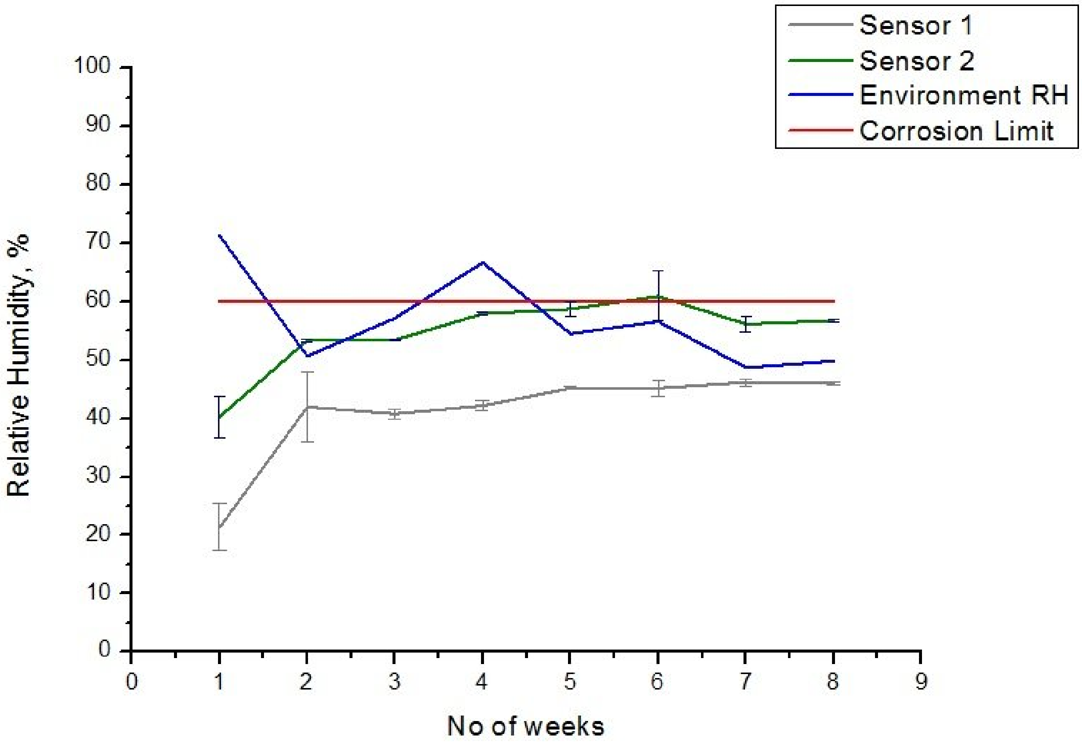


Fig. 14. Graph of Relative Humidity measured underneath composite material for test jig design by UTP

Based on the data obtain throughout the experiment, eventhough capacitive humidity sensors were placed underneath wet composite material, both sensors still able to provide data within RH limit (0%-100%). Thus, shows that the capacitive humidity sensor is not being affected by liquid substance exist at the surface of the composite material.

Data tabulated in Table 6 shows that the average humidity level underneath composite material is lower than normal surrounding RH measured using similar type of humidity sensor. However, the data shows there are quite huge difference in capacitance value between humidity sensor 1 and humidity sensor 2. In terms of precision, the standard deviation the first two weeks for Sensor 1 and first week for Sensor 2 is lower than other week. This is because of the period of time for the primer and the composite material to solidify and stabilize.

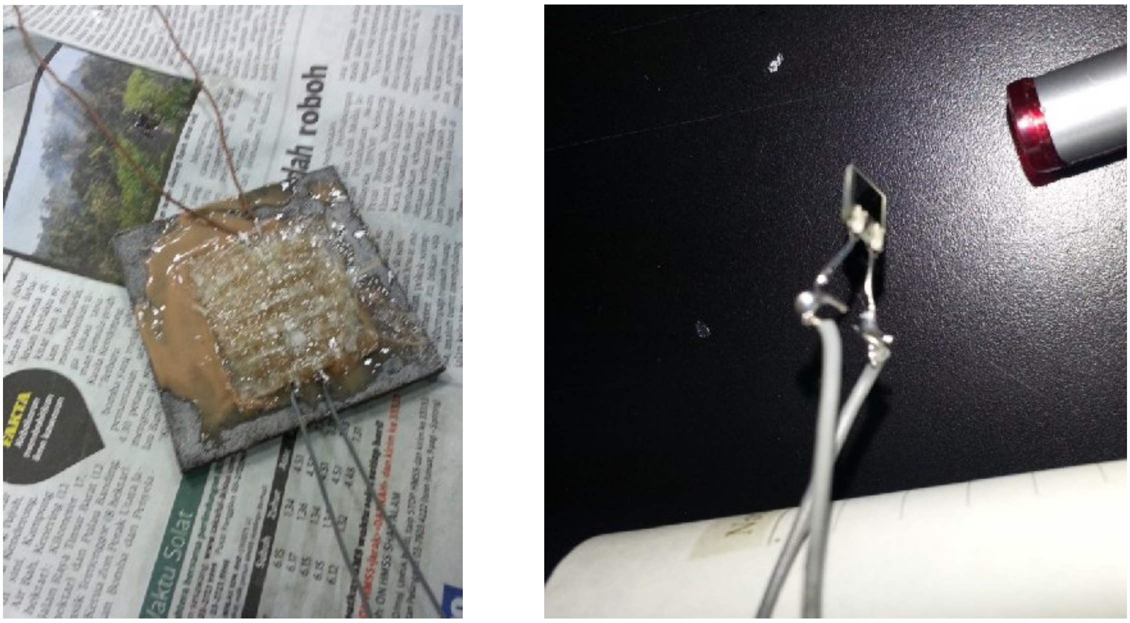


Fig. 15. Capacitive Humidity sensors connected with wires and placed under wet composite material

In addition, the average amount of RH underneath composite material lower than the corrosion limit RH, reduced by composite materials, which is 60%, hence, indicate the technique used by UTP is suitable to be implemented alongside humidity sensors underneath composite material to measure the amount of RH.

However, since the technique used by UTP is differ with the technique implemented by IOSSB during the installation of composite wrapping, another test jig was design and set up by IOSSB to determine whether the sensors will still manage to deliver the expected amount of capacitance underneath composite material using their installation procedure.

4.3.2 Humidity Sensor Testing underneath Composite Material design by IOSSB

As the data collected from the test jig design by UTP has proven that the sensors were able to measure and provide the amount of RH underneath wet composite wrapping, this experiment was designed to determine the functionality of the sensors underneath wet composite material by using the technique implemented by IOSSB.

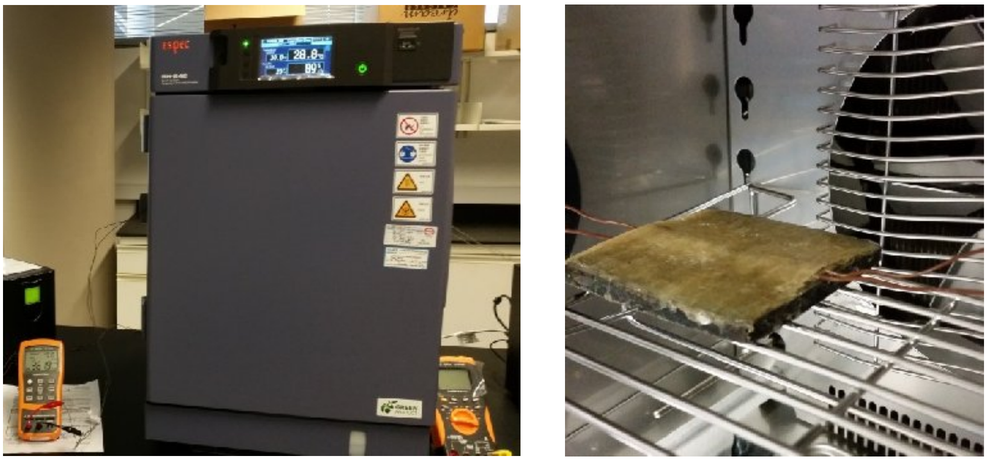


Fig. 16. ESPEC SH-242 temperature and humidity chamber

The experiment of collecting data from sensors installed in IOSSB test jig is done by using ESPEC SH-242 Temperature and Humidity Chamber. The chamber is able to control and varies both temperature and RH. Hence, the chamber is suitable to be used to commence RH variation and temperature variation testing to the test jig.

In addition, the purpose testing at RH variation and temperature variation is to know whether the sensors were still function properly and whether the composite material is able to protect the sensors and the metal plate from very high or very low amount of RH surround the test jig.

4.3.2.1 Testing at atmospheric environment condition

The technique used to extract the RH value from humidity sensor tested underneath wet composite material for IOSSB test jig is similar to the technique used to collect the RH data from humidity sensor for UTP test jig. This experiment was done in two places, inside CCR and also at the outside.

Table 10: Humidity sensor underneath composite material testing for atmospheric environment condition

Date	Average Cap. Value, , pF	Average Sensor RH, %	Average Sensor Environment RH, %	Standard Deviation,
Humidity Sensor 1				
14/7	341.58 pF	74.82%	67.06%	2.16
16/7	340.40 pF	72.87%	51.58%	1.03
23/7	335.62 pF	66.19%	63.98%	0.54
1/8	338.96 pF	71.18%	73.78%	1.02
4/8	336.98 pF	67.65%	62.88%	0.54
9/8	338.82 pF	70.32%	64.88%	2.51
12/8	339.96 pF	72.45%	69.52%	0.47
Humidity Sensor 2				
14/7	327.94 pF	61.65%	67.12%	0.57
16/7	324.48 pF	56.72%	51.50%	0.80
23/7	326.78 pF	60.52%	64.08%	0.82
1/8	334.18 pF	69.46%	73.78%	0.77
4/8	332.90 pF	67.63%	62.78%	0.18
9/8	331.20 pF	65.95%	64.82%	0.55
12/8	334.14 pF	69.77%	69.54%	0.73
Humidity Sensor 3				
14/7	360.16 pF	86.74%	66.88%	0.71
16/7	360.52 pF	86.94%	51.96%	0.73
23/7	355.52 pF	81.86%	63.78%	1.21
1/8	354.00 pF	80.14%	73.78%	0.57
4/8	352.08 pF	78.47%	62.50%	0.70
9/8	360.72 pF	88.25%	64.68%	4.62
12/8	358.56 pF	84.86%	69.54%	1.04
Humidity Sensor 4				
14/7	363.62 pF	92.30%	66.90%	1.92
16/7	360.6 pF	86.98%	51.82%	0.61
23/7	355.84 pF	82.29%	63.82%	1.21
1/8	352.40 pF	78.89%	73.78%	0.75
4/8	351.12 pF	78.27%	62.64%	0.51

9/8	355.44 pF	81.59%	64.88%	1.82
12/8	353.96 pF	81.08%	69.70%	0.30

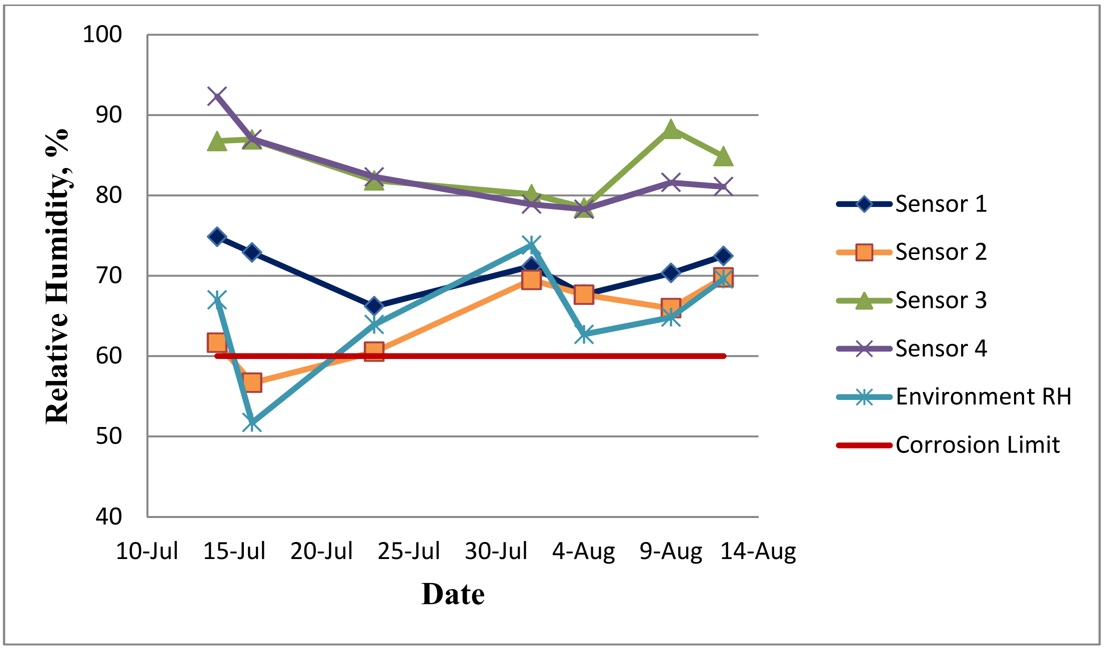


Fig. 17. Graph of IOSSB test jig testing for atmospheric environment condition

The data and the graph shows that all four sensors installed underneath wet composite material for test jig designed by IOSSB are higher than the RH limit, which is 60 %. However, Sensor 2 indicates the RH lower than corrosion limit, but only during second experiment.

The RH data extracted from sensors installed for IOSSB design were differ with the RH collected from UTP design. The differences in RH obtain from both UTP and IOSSB was due to the technique implemented by both parties. While UTP put the final layer of composite material without the need to roll the composite on top of the sensors, IOSSB used the procedure they have been used during the installation of composite material wrapped around the corroded pipeline in the industry by rolling several layers of composite material on top of the sensors.

Hence, the rolling technique, which will compress the composite material and pressed the sensors underneath the composite material, is the reason why the RH underneath composite material is high. With the humidity sensor placed underneath the composite wrapping, the rolling technique, which was supposed to remove bubbles or air underneath the composite wrappings, eventually trapped the air that contain RH and reduces the rate of vaporization. Furthermore, due to hard compression, the technique might also damages the sensors.

In addition, the pattern of RH underneath composite material, provided by humidity sensors, shows that it follows the surrounding RH. Hence, RH variation is necessarily need to be done in order to determine whether RH underneath composite material did follow the surrounding RH due to the design made by the IOSSB or not.

Apart from that, RH variation and temperature variation will also need to be done in order to determine whether the RH underneath composite material is actually higher than the corrosion limit, as shown in the data and the graph obtain, or the rolling method damages the sensors and hence, unable to determine the actual RH.

4.3.2.2 Testing for RH variation

The test jigs were tested with RH variation from 25% to 80% with fixed temperature (30℃) inside controlled humidity and temperature chamber. The result obtain throughout the experiment was tabulated and presented as graph below.

Table 11: Humidity sensor underneath composite material tested for RH variation

No	Average Cap. Value, , pF	Average Sensor RH, %	Average Environment RH, %	Standard Deviation,
Humidity Sensor 1				
1	336.82 pF	67.37%	25%	0.72
2	337.34 pF	68.27%	40%	1.17
3	337.68 pF	68.86%	60%	0.39
4	337.06 pF	67.78%	80%	0.19
Humidity Sensor 2				
1	327.38 pF	61.17%	25%	0.48
2	330.24 pF	64.58%	40%	0.51
3	330.22 pF	64.55%	60%	0.31
4	329.96 pF	64.16%	80%	0.23
Humidity Sensor 3				
1	360.62 pF	87.43%	25%	0.32
2	360.08 pF	86.32%	40%	0.08
3	360.44 pF	87.03%	60%	0.74
4	358.12 pF	84.81%	80%	0.30

Humidity Sensor 4				
1	361.34 pF	88.15%	25%	0.29
2	361.44 pF	88.30%	40%	0.49
3	361.70 pF	88.70%	60%	0.54
4	360.16 pF	87.42%	80%	0.24

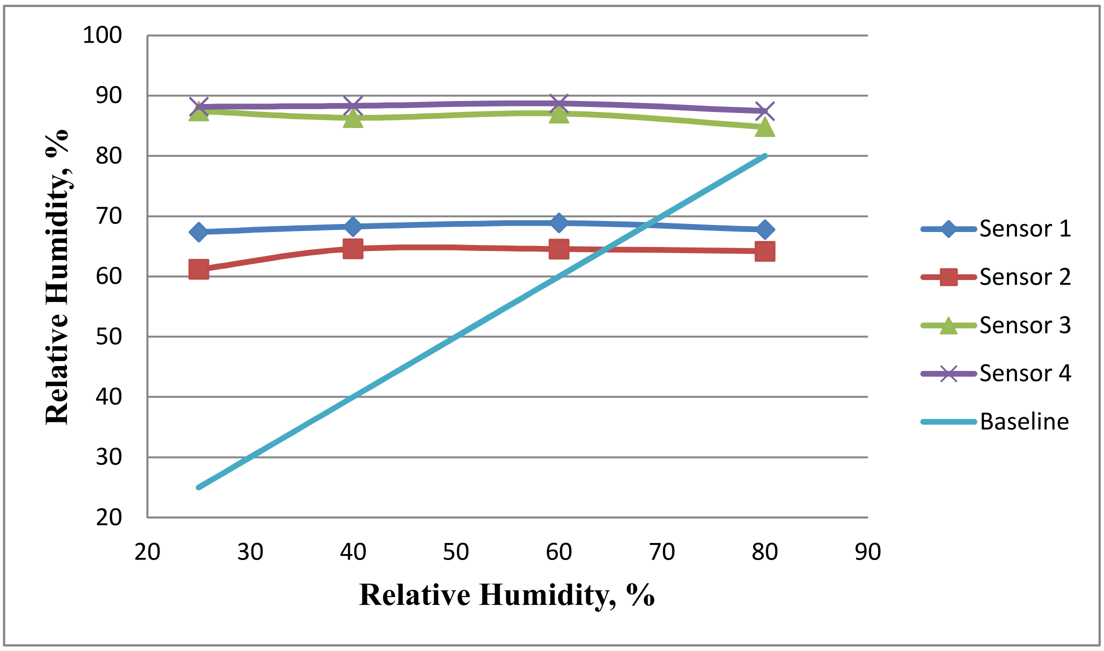


Fig. 18. Graph of IOSSB test jig testing for RH variation

The purpose of having RH variation testing is to determine whether or not the RH underneath composite material was affected by the changes of surrounding RH and whether the test jig design itself were able to protect the sensors from surrounding RH.

Data collected from all 4 sensors placed underneath composite material shows the amount of RH maintains as the RH varies inside the chamber. This proves that the amount of RH underneath composite material was not affected by external or surrounding RH around the test jig.

The data also shows that the sensors were placed deep inside the test jigs. Hence, surrounding RH will not change the sensors' dielectric constant. Hence, prove that the composite material used to wrap the pipeline will protect the metal pipeline as well as the sensors from external RH variation.

4.3.2.3 Testing for Temperature Variation

The test jigs were tested with temperature variation inside controlled humidity and temperature chamber alongside fixed surrounding RH (60% RH) to determine whether the sensors were still able to provide different amount of capacitance or was damaged due to the technique implemented by IOSSB.

The result obtain throughout the experiment was tabulated and presented as graph below.

Table 12: Humidity sensor underneath composite material tested for temperature variation

No	Average Cap. Value, , pF	Datasheet capacitance, pF	Temperature, °C	Standard Deviation,
Humidity Sensor 1				
1	341.48 pF	332.94 pF	25°C	0.43
2	340.58 pF	329.41 pF	50°C	0.33
3	335.08pF	326.56 pF	75°C	0.83
4	334.96 pF	324.80 pF	90°C	0.32
Humidity Sensor 2				
1	336.32 pF	332.94 pF	25°C	0.33
2	335.50 pF	329.41 pF	50°C	0.44
3	327.38 pF	326.56 pF	75°C	1.17
4	324.36 pF	324.80 pF	90°C	1.30
Humidity Sensor 3				
1	362.22 pF	332.94 pF	25°C	0.41
2	360.90 pF	329.41 pF	50°C	0.48
3	361.88 pF	326.56 pF	75°C	0.46
4	360.26 pF	324.80 pF	90°C	0.98
Humidity Sensor 4				
1	353.20 pF	332.94 pF	25°C	0.12
2	354.10 pF	329.41 pF	50°C	0.45
3	351.16 pF	326.56 pF	75°C	1.01
4	349.48 pF	324.80 pF	90°C	0.79

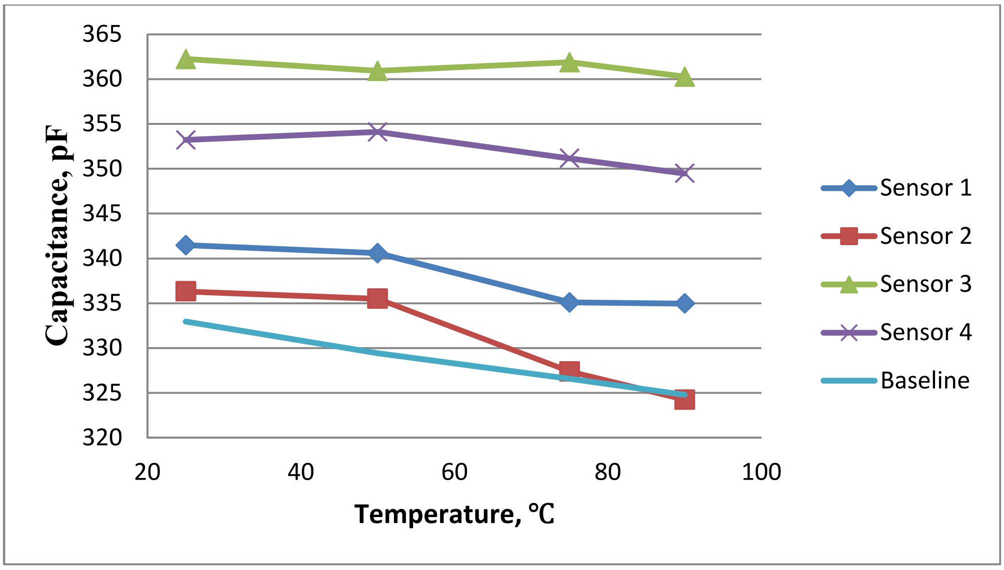


Fig. 19. Graph of IOSSB test jig testing for temperature variation

The reference baseline provided by the supplier (Honeywell) shows that the amounts of capacitance of capacitive humidity sensor are supposed to decrease with respect to the increase in the surrounding temperature.

Based on the data obtain, the decrease in the amount of capacitance for Sensor 1 and Sensor 2 indicate that both sensor function properly underneath composite material. Similar to Sensor 1 and Sensor 2, Sensor 4 is also able to provide data since the amount of capacitance decreases with the increase in temperature. Hence, shows that the RH obtain from the sensors tested in the atmospheric condition is valid and show the actual RH underneath composite material. However, Sensor 3 fails to provide the expected pattern of capacitance. This may be because of the damage occurs inside the capacitive humidity sensor.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

Two type of capacitive humidity sensor were tested and characterized throughout the execution of the project, which is MK-33 and HCH-1000. However, only HCH-1000 was implemented underneath composite material for both test jig design by Center of Corrosion Research (CCR) from UTP and by Innovative Oilfield Services Sdn Bhd (IOSSB).

Overall result shows that based on UTP wrapping method, two humidity sensors installed underneath composite material manage to deliver the expected Relative Humidity (RH) which below 60%, meaning that the wrapping technique without hard compression to the humidity sensors will enable the sensors to read the actual amount of RH underneath wet composite material.

Based on sensors implemented inside IOSSB test jigs, the sensors were somehow unable to provide the expected value of RH underneath composite material, as all the sensors provide higher value than the corrosion limit (60% RH). This is due to their wrapping technique, as it is tightly wrapped, causes low rate of evaporation for humidity underneath composite material.

However, the fact that the sensors are able to function properly in spite of having high amount of RH proves that installing humidity sensor technique to determine the integrity of the pipeline and the composite wrapping can be applied to the industry. Hence, to ensure the sensors are able to deliver recommended data, several procedure need to be added and strictly followed, such as manually remove air around the sensors without rolling the top of the sensors and also completely cover the humidity sensor with composite wrapping.

For future recommendation, the project is recommended to be executed in the industrial-scale measurement. This will determine the functionality of humidity sensors during the actual installation of composite material wrapped around the pipeline. In addition, the other two types of humidity sensors, which are thermal-type and resistive-type humidity sensor, can also be considered to be tested for the project.

CHAPTER 6: REFERENCES

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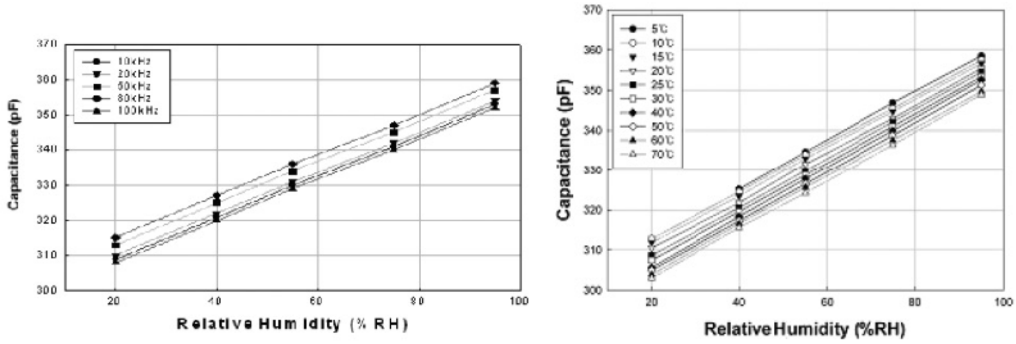
CHAPTER 7: APPENDICES

No	Company	LC Meter Kit Name	Capacitor Range (pF)	Frequency (Hz)	Weight(g)	Price (RM)	Designated link	Availability (Origin)	Remarks	Picture
1	Agilent	U1733C	20pF–20mF	100Hz–100kHz	337	RM1,476	RS Component	Malaysia	Based on datasheet. Include Aligator clip leads and 9V alkaline battery.Need to add U1730A (AC Power Adapter)	
2		U1732C	20pF–20mF	100Hz–10kHz	337	RM1,289	RS Component	Malaysia	Based on datasheet. Include Aligator clip leads and 9V alkaline battery.Need to add U1730A (AC Power Adapter)	
3		U1733C	20pF–20mF	100Hz–100kHz	337	RM1,476	Element14	Singapore & UK	Based on datasheet. Include Aligator clip leads and 9V alkaline battery.Need to add U1730A (AC Power Adapter)	
4		U1732C	20pF–20mF	100Hz–10kHz	337	RM1,302	Element14	UK	Based on datasheet. Include Aligator clip leads and 9V alkaline battery.Need to add U1730A (AC Power Adapter)	
5		U1733C	20pF–20mF	100Hz–100kHz	337	RM1,500	Agilent Technologies	Malaysia	Should include Aligator clip leads, 9V alkaline battery and AC Power Adapter	
6		U1732C	20pF–20mF	100Hz–10kHz	337	RM1,317	Agilent Technologies	Malaysia	Should include Aligator clip leads, 9V alkaline battery and AC Power Adapter	
7	Motech	MT 4080	0pF–9999F	100Hz–100kHz	470	RM5,306	Element14		No longer manufactured	
8	Tongu (China)	TH2821A	0.01pF–9999uF	100Hz–10kHz	400	$328	GlobalMediaPro	Singapore	Include battery & power supply	

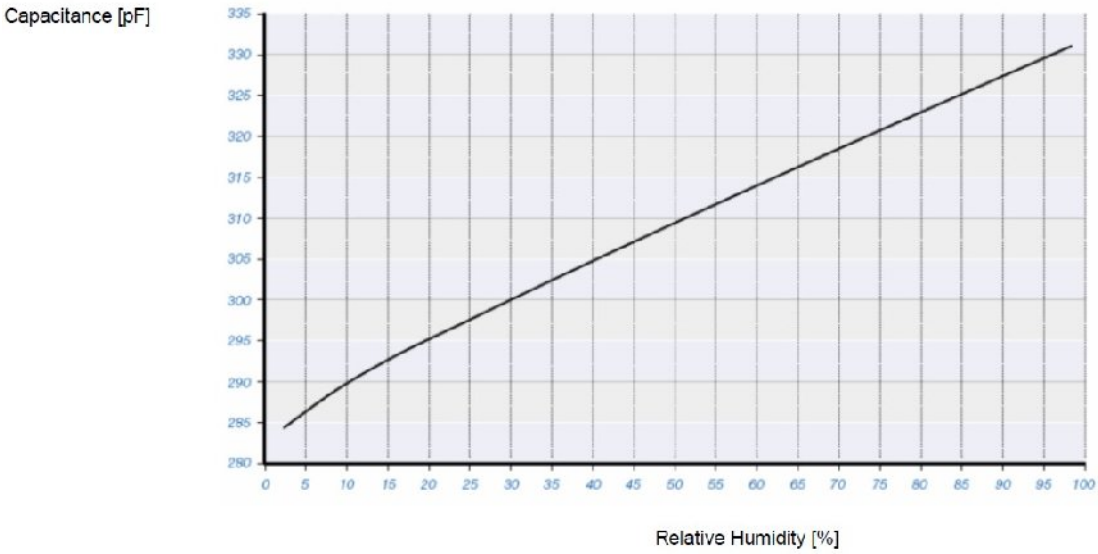
1) LCR Meter Kit Comparison

No	Company	Sensor Name	Capacitor Range (pF)	Frequency (Hz)	Humidity Range(%) / Temperature Range (C)	Dimension, mm Head (Width x Depth x	Dimension, mm Leg (Gap, Width x Depth x Height)	Price (RM)	Designated lin	Availability (Origin)	Remarks	Picture
1	Honeywell	HCH-1000-001	310-350	10k / 100k	0 - 100 / -40 - 120	5x0.65x7	2.54, 0.5x0.3x11	15.54	element14	Singapore	Response time = 15sec Supply Vrms = 1	
2		HCH-1000-002				6.52x2.36x10.18	2.54, 0.5x0.3x8.5	15.91				
3		HIH-4000-001	Voltage output (0.8-3.7)		0 - 100 / -40 - 85	4.17x2.03x8.59	2.54,2.54, 0.38(diameter)x12	88.15	element14	Singapore & UK	Response time = 15sec Supply Vdc=4 – 5.8	
4		HIH-4000-002				4.17x2.03x8.59	1.27,1.27, 0.38(diameter)x12	93.92		Singapore & UK	Response time = 15sec Supply Vdc=4 – 5.8	
5		HIH-4000-003				4.17x2.03x8.59	2.54,2.54, 0.38(diameter)x12	102.03		Singapore & UK	Response time = 5sec Supply Vdc = 4 – 5.8	
6		HIH-4000-004				4.17x2.03x8.59	1.27,1.27, 0.38(diameter)x12	89.37		HK & UK	Response time = 5sec Supply Vdc = 4 – 5.8	
7	IST Innovative Technology	YK33 (300PF +/-400PF)	280 - 340	10k(1k-100k)	0 - 100 / -40 - 150	3.8x0.4x1.8	10(height)	175.55	element14	UK	Response time=5sec Supply Vp-peak= 12 max	
8		P14 (150PF +/-50PF)	130-170	10k(1k-100k)	0-100 / -50 – 150	3.0x0.4x5	10(height)	107.72	element14	UK	Response time = 5sec Supply Vp-peak= 12 max	
9	Measurement Specialties	HS1101LF (fi	161.6 - 183.1	10k(5k-300k)	0-100 / -60 – 140	10.2x10.2x3.2	5.33, 0.5(diameter)x14	7.29 – 14.12 (US)	Endchips (Components Distribution Recommend	US (main)	Supply Vac = 10	

2) Capacitive Humidity Sensor Comparison



3) Frequency and Temperature Characteristics for HCH-1000 Humidity Sensor



4) Frequency Characteristics for MK-33 Humidity Sensor