Investigation of the Relationship between Electrical Conductivity and Total Dissolved Solids for Mono-Valent, Di-Valent and Tri-Valent Metal Compounds

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Abstract: **This study investigated the relationship that exist between total dissolve solids (TDS) and electrical conductivity (EC) for mono-, di- and tri-valent metal compounds. Standard solution of soluble and ionizable representatives of these different valency metal compounds (NaCl, $CaCl_2$, $FeCl_2.4H_20$) were prepared and there EC and TDS values were obtained at different concentrations with a suitable EC/TDS meter. Increase in EC and TDS values follows the trend, at 0.01M NaCl, EC is 1.4ms/cm, TDS is 0.8ppm. At 0.1M$CaCl_2$, EC is 2.36ms/cm, TDS is 1.43ppm. At 0.1M$FeCl_2.4H_20$ EC is 2.36ms/cm, and TDS is1.57ppm. From the data obtained, mathematical model was established for the different valency metal compounds to state the relationship between EC and TDS. For each of the compounds an appropriate model to state the relationship are, for mono-valent metal compound NaCl, (EC = 0.052672+1.5025.TDS), di-valent metal compound, $CaCl_2$ (EC= 1.072 + 131.TDS) and tri-valent metal compound, $FeCl_2$. $4H_20$ (EC = 0.0251879 + 1. 49308 TDS) such that with a solution of such metal compound the value of EC or TDS can be approximately calculated and ascertained from the other.**

Keywords: **Electrical Conductivity, Metal, Model, Total Dissolved Solids.**

I. INTRODUCTION

Natural waters contain a variety of both ionic and uncharged species in various amounts and proportions that constitute the dissolved solids. Thus it is not clear whether specific conductance measurements can be used to obtain accurate estimates of TDS. In addition, the effect of dissolved diesel on TDS measured by both the gravimetric and conductivity/TDS meter techniques needed to be determined using standard electrolyte solutions [1] (Atekwanaa et al, 2004).

TDS of natural waters can be measured by standard gravimetric techniques or by the use of conductivity/TDS meters. The specific conductance (electrical conductivity normalized to 25 8C) of groundwater is directly related to the TDS based on the assumption that TDS in the water consist mainly of ionic constituents that conduct electricity [2,3,4] (Wood, 1976, Lloyd and Heathcote, 1985 & Hem, 1985).

The term TDS describes all solids (usually mineral salts) that are dissolved in water. The TDS and the electrical conductivity are in a close connection. The more salts are dissolved in the water, the higher is the value of the electric conductivity. The majority of solids, which remain in the water after a sand filter, are dissolved ions. Sodium chloride for example is found in water as Na+ and Cl-. High purity water that contains in the ideal case only H2O without salts or minerals has a very low electrical conductivity. The water temperature affects the electric conductivity so that its value increases from 2 up to 3 % per 1 degree Celsius [5] (lennetech.com).

Total dissolved solids are differentiated from total suspended solids (**TSS**), in that the latter cannot pass through a sieve of two micrometers and yet are indefinitely suspended in solution [6] (DeZuane, 1997).

According to smart-fertilizer.com, the electrical conductivity of water estimates the total amount of solids dissolved in water.

-TDS, which stands for Total Dissolved Solids. TDS is measured in ppm (parts per million) or in mg/l [7] (smart-fretilizer.com).

A. Factors Affecting the Electrical Conductivity of Water:

The electrical conductivity of the water depends on the water temperature: the higher the temperature, the higher the electrical conductivity would be. The electrical conductivity of water increases by 2-3% for an increase of 1 degree Celsius of water temperature. Many EC meters nowadays automatically standardize the readings to 25^{o}C.

While the electrical conductivity is a good indicator of the total salinity, it still does not provide any information about the ion composition in the water. The same electrical conductivity values can be measured in low quality water (e.g. water rich with Sodium, Boron and Fluorides) as well as in high quality irrigation water (e.g. adequately fertilized water with appropriate nutrient concentrations and ratios). The commonly used units for measuring electrical conductivity of water are:

µS/cm (microSiemens/cm) or dS/m (deciSiemens/m)

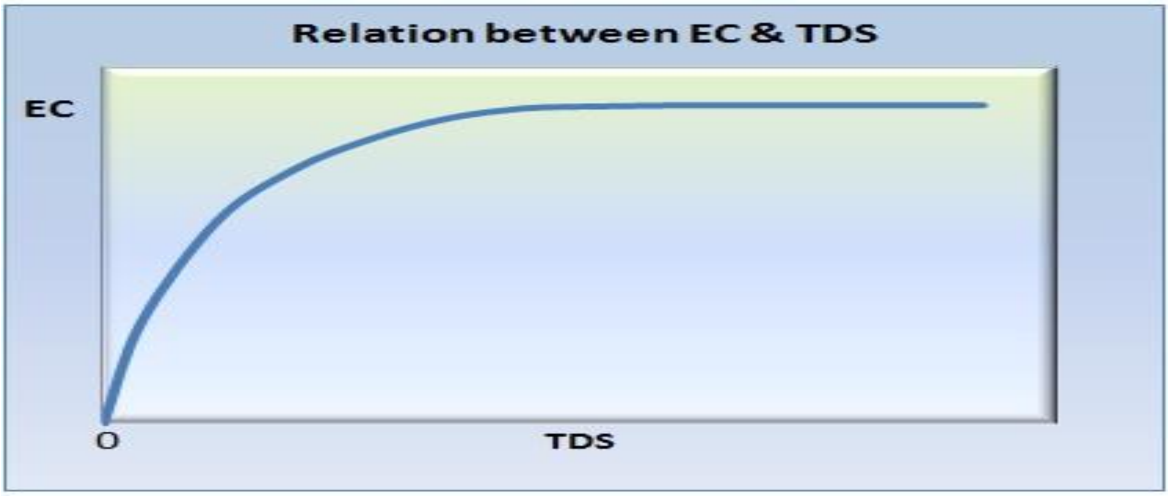
Where: 1000 µs/cm = 1 dS/m

TDS and Electrical Conductivity

Since the electrical conductivity is a measure to the capacity of water to conduct electrical current, it is directly related to the concentration of salts dissolved in water, and therefore to the Total Dissolved Solids (TDS). Salts dissolve into positively charged ions and negatively charged ions, which conduct electricity.

Since it is difficult to measure TDS in the field, the electrical conductivity of the water is used as a measure. The electrical conductivity of the water can be determined in a quick and inexpensive way, using portable meters. Distilled water does not contain dissolved salts and, as a result, it does not conduct electricity and has an electrical conductivity of zero.

Nevertheless, when the salt concentration reaches a certain level, electrical conductivity is no longer directly related to salts concentration. This is because ion pairs are formed. Ion pairs weaken each other's charge, so that above this level, higher TDS will not result in equally higher electrical conductivity.



EC can be converted to TDS using the following calculation:

TDS (ppm) = 0.64 X EC (µS/cm) = 640 X EC (dS/m)

This relation provides an estimate only.

Electrical conductivity of water is directly related to the concentration of dissolved ionized solids in the water. Ions from the dissolved solids in water create the ability for that water to conduct an electrical current, which can be measured using a conventional conductivity meter or TDS meter. When correlated with laboratory TDS measurements, conductivity provides an approximate value for the TDS concentration, usually to within ten-percent accuracy.

The relationship of TDS and specific conductance of groundwater can be approximated by the following equation:

$TDS = k_e EC$

Where TDS is expressed in mg/L and EC is the electrical conductivity in microsiemens per centimeter at 25° C. The correlation factor k_e varies between 0.55 and 0.8 [8] (epa.gov).

II. PRACTICAL IMPLICATIONS

High TDS levels generally indicate hard water, which can cause scale buildup in pipes, valves, and filters, reducing performance and adding to system maintenance costs. These effects can be seen in aquariums, spas, swimming pools, and reverse osmosis water treatment systems. Typically, in these applications, total dissolved solids are tested frequently, and filtration membranes are checked in order to prevent adverse effects [9] (wikipedia.org).

TDS is often monitored in order to create a water quality environment favorable for organism productivity. For freshwater oysters, trouts, and other high value seafood, highest productivity and economic returns are achieved by mimicking the TDS and pH levels of each species' native environment. For hydroponic uses, total dissolved solids is considered one of the best indices of nutrient availability for the aquatic plants being grown .

Because the threshold of acceptable aesthetic criteria for human drinking water is 500 mg/l, there is no general concern for odor, taste, and color at a level much lower than is required for harm. A number of studies have been conducted and indicate various species' reactions range from intolerance to outright toxicity due to elevated TDS. The numerical results must be interpreted cautiously, as true toxicity outcomes will relate to specific chemical constituents. Nevertheless, some numerical information is a useful guide to the nature of risks in exposing aquatic organisms or terrestrial animals to high TDS levels. Most aquatic ecosystems involving mixed fish fauna can tolerate TDS levels of 1000 mg/l [10,11.12,13] (Boyd, 1999, Kaiser Engineers, 1969, IAC, 2003 & Hogan et al, 1973).

III. METHODOLOGY

This research work focus on the relationship that may exist between TDS and EC. So as prepare care is taken to prepare solution of various valency metal compounds.

Determination of the conductivity and TDs volumes of the various samples using the conductivity/TDs meter.

The samples are representatives of different valences of metals For mono-valent, a mono-valent meter compound (NaCl) was used. For divalent metal compound, calcium chloride, anhydrous was used and for trivalent iron (4) chloride tetrahy drate was used, these also represent a variable valiancy.

Different concentrations of this sample were prepared (0.01M, 0.02M, 0.03M, 0.04M and 0.05M respectively).

The conductivity/TDS meter was calibrated using a Solution of 0.01M kcl in de-ionized water which gave a conductivity of 1.413ms/cm. at 25^0c

IV. RESULT AND DISCUSSION

The following tables show the experimental reading from the analysis.

Table (1) shows conductivity and TDs values of Nacl solution at different concentration for a mono-valent metal compound (NaCl)

S/N	Conc of anhydrous Nacl (m)	Conductivity (ms/cm)	TDs (PPM)	Qty
1	0.01	1.413	0.89	100ml
2	0.02	2.53	1.68	100ml
3	0.03	3.72	2.47	100ml
4	0.04	4.35	2.89	100ml
5	0.05	5.35	3.56	100ml

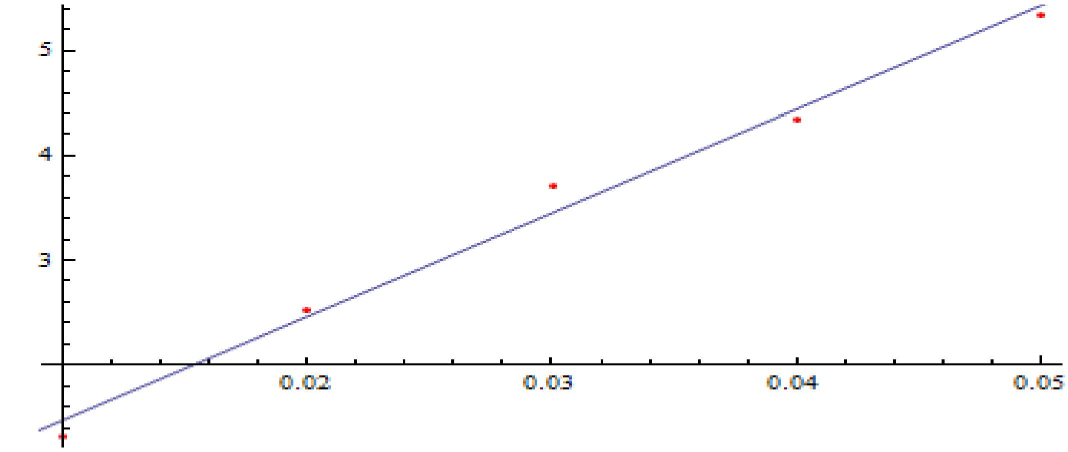


Fig 1: Graph of Cond vs Conc for NaCl

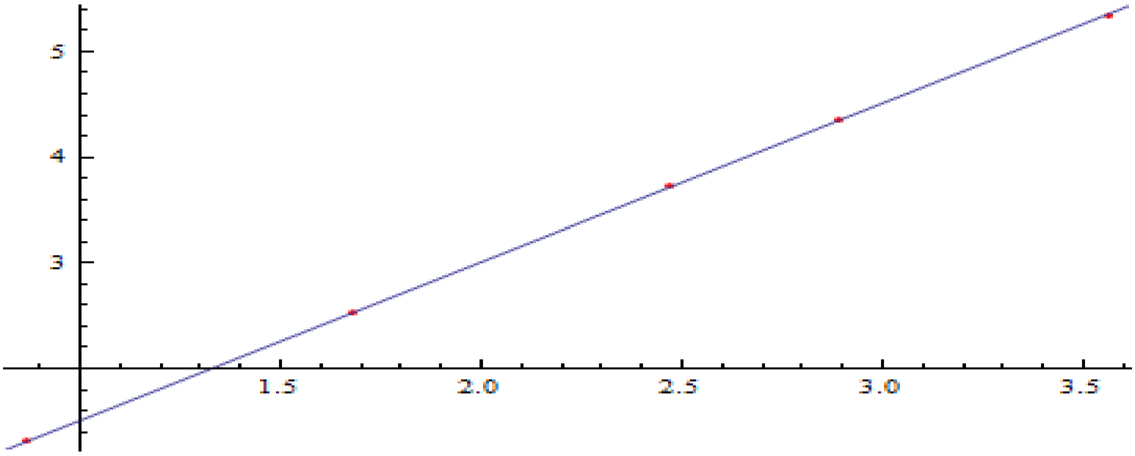


Fig 2: Graph of cond vs TDS for NaCl

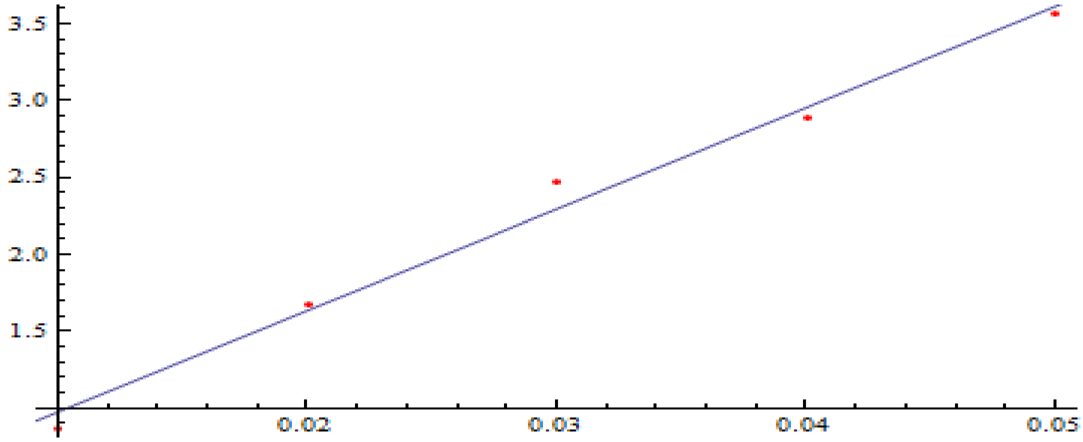


Fig 3: Graph of Conc Vs TDS for NaCl

Table (2) shows conductivity and TDs values for divalent metal compound ($CaCl_2$ anhydrous).

S/N	Conc of $CaCl_2$ anhydrous (m)	Conductivity (ms/cm)	TDs (PPM)	Qty
1	0.01	2.14	1.43	100ml
2	0.02	3.89	259	100ml
3	0.03	5.13	3.42	100ml
4	0.04	6.43	4.29	100ml
5	0.05	7.42	4.94	100ml

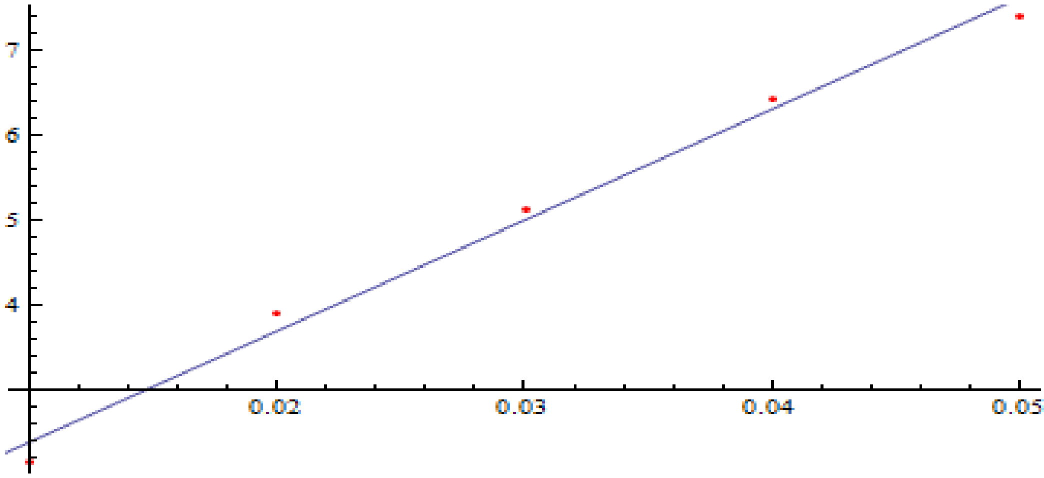


Fig 4 Graph of cond vs Conc for $CaCl_2$

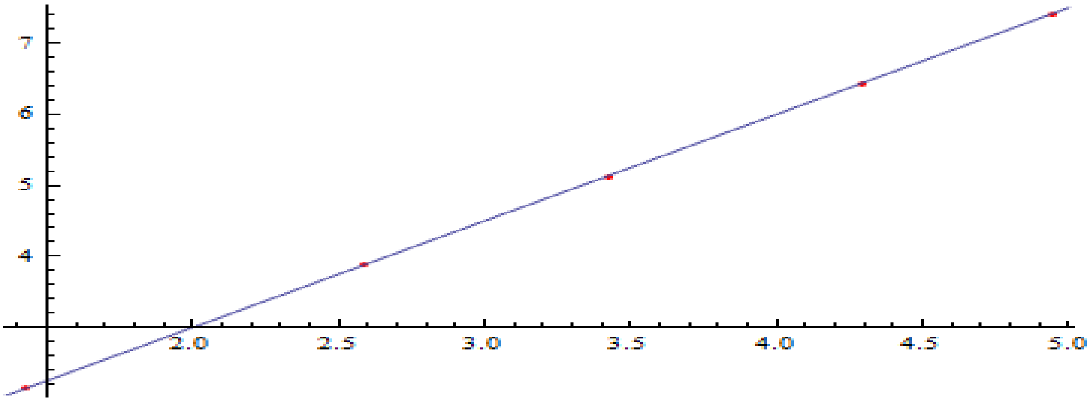


Fig 5: Graph of TDS vs Cond for $CaCl_2$

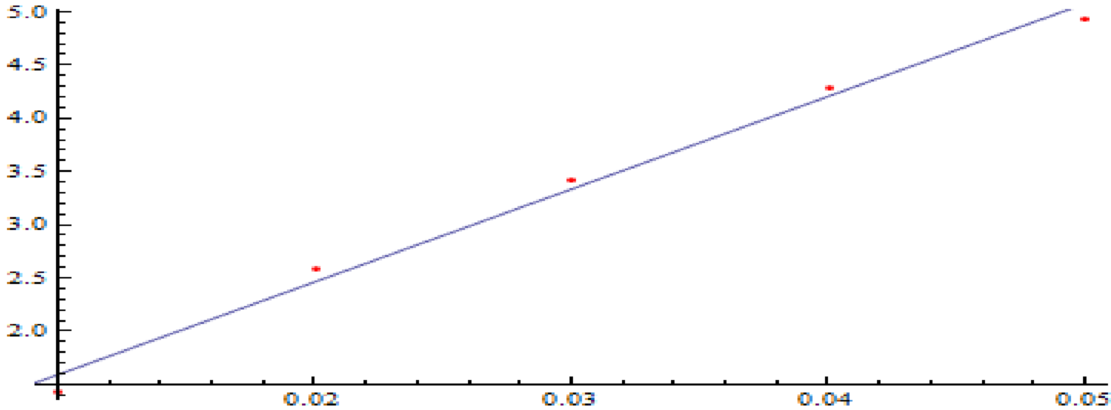


Fig 6: Graph of TDS vs conc CaCl2

Table (3) shows conductivity and TDs values for a trivalent metal compound ($FeCl_2.4H_20$), the following result were obtained.

S/N	Conc. of $FeCl_2.4H_20$ (m)	Conductivity (ms/cm)	TDS (PPM)	Qty
1	0.01	2.36	1.57	100ml
2	0.02	4.41	2.93	100ml
3	0.03	5.28	3.51	100ml
4	0.04	7.05	4.72	100ml
5	0.05	8.20	5.47	100ml

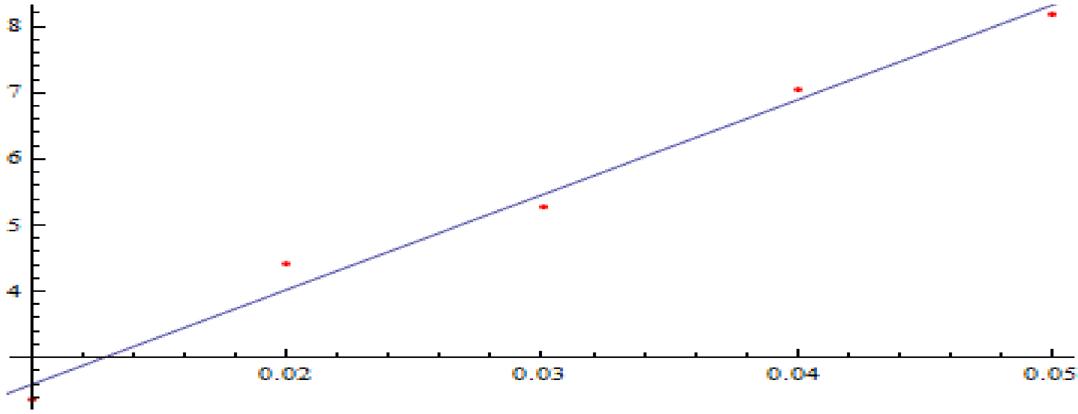


Fig 7: Graph of cond vs Conc for $FeCl_2.4H_2O$

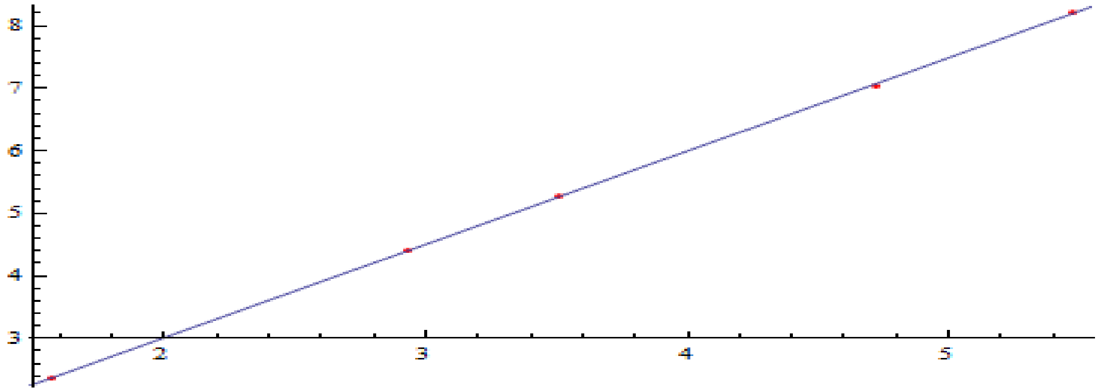


Fig 8: Graph of cond vs TDS for $FeCl_2.4H_2O$

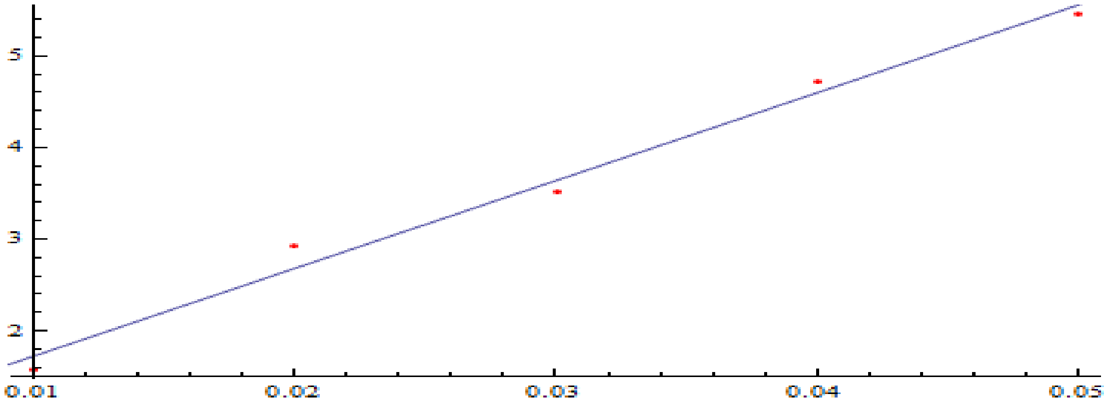


Fig 9: Graph of TDS vs Conc for FeCl2.4H2O

V. DISCUSSION

From the results obtained the relationship between conductivity and total dissolved solid TDS are observed as follows:

Increase in concentration of metal compounds whether mono-valiant, divalent or trivalent metal compound increased the conductivity values for example in 0.01m Nacl the conductivity increased 0.02m Nacl, the conductivity, increased in an undetermined preparation.

There is a clear indication that as the valency of metal compound solution increase via mono-valiant to divalent to trivalent, the conductivity increased also. At the same concentration a Divalent metal compound 0.02m $CaCl_2$ anhydrous has a conductivity value of 3.89ms/cm, a Monovalent compound of 0.02mNacl has a conductivity of 2.53 while a Trivalent compound of 0.02 $FeCl_2$-$4H_20$ have a conductivity of 4.41ms/cm. This fact is corroborated with many literatures. For the relationships between parameters there were to clear relationship between TDS and conductivity as propose a mathematical model (Empirical).

A. A Mathematical Model to Represent the Relationship between TDS and EC:

A mathematical model is supply mathematical representation of a real life system in order to gain more insight into the system and, in most cases, brings about solutions to problem or system under consideration [14] (Okuonghae, 2011).

The model could be sample algebraic equations, difference equations, and ordinary equations, integral equations or even a mixture of these.

From the data obtained in the experimental work. A graph of E.C against concentration and TDS was plotted for the various valence metal compounds a lineal graph was obtained and considering a (Fowler 2004) simple case, if y is proportional to and proportional to , then the appropriate mathematics expression to represent the relationship where is the constant of proportionality. This case if y is doubled whenever or is doubled, however if y is increases by an amount whenever there is a unit increase in and by an amount , for every unit increase in then an appropriate mathematical form will be Using these ideal and from the information obtained from the graph, this made us to finalised that a simple algebraic equation mode could be used. i.e. an equation of the form.

Where an are red numbers.

From the information obtained from the graph (i.e. slopes, intercept) we say

Let y be the electrical conductivity EC, x_1 be the concentration C, x_2 be the total dissolved solids TDS An appropriate mathematical model for this variable are.

$Y = a + bx_1 + C$

Where a,b and c are constants that depend on the specific valency of the metal compounds also a suitable representation for y ganist the other variables may seen to be

And $y=a_3+b_3x_1+b_4x_2$. (where a_1, a_2, a_3 b_1, b_2,b_3 b_4 are constants)

Therefore for a divalent metal compound recall a mathematic model (Empiric) to state the relationship between EC and T.DS is

Where EC= electrical conductivity for divalent metal compound

C= concentration for a divalent metal liquid total dissolve solid value for a divalent metal compound solution.

Equation (2) is the mathematical relationship between E.C and TDS for a divalent metal compound solution Equation (3) is the general.

For a monovalent metal compound

Where

= conductivity of a monovalent metal compound

= conc. of monovalent metal compound to solar.

= total dissolve solid of the monovalent metal compound in the solution.

Equation is a mathematical model stating the relationship between EC and TDS for a monovolent metal compound in solution.

For a trivalent metal compound a mathematical model stating the relationship between EC Conc. And TDS are given below.

= 0.025189 t1.49308.TDS

Where

TDS= total dissolve solids of the trivalent metal compound in solution

B. Importance's of the Model:

This mathematical model helps to approximately determine TDS of any monovalent, divalent, trivalent. Metal compound from the E.C value obtained, on the other way round when the TDS is known the E.C. con be determined The equations above directly related the concentration, TDS and the E.C for these different metal valency compounds in solution, the first equation of each relates concentration to EC, the last three equations relates TDS to concentration for each of the compounds.

VI. SHORT-COMINGS

The different equation worked separated for a particles valence related compound solution non of the equation could relate or stand for a relationship for E.C and TDS for all valence metal compound.

The model could not be used to find a relationship between TDS and E.C of a multi – compound solution and waste water

However, the model stood approximately for many different valence metal compound solutions.

VII. CONCLUSION

The assumption that the TDS of water samples based on measured EC value can be calculated using the equation.

TDS (Mg/L (ppm) = 0.5 x EC is proved wrong here because we saw a situation where by electrical conductivity and TDS were equal in water sample. lenntech also stated that at high TDS values the ratio TDS/EC increase and the relationship tends towards TDS = 0.9 x EC is proven not to be true here since at higher TDS there were also were we had TDS and EC equal.

The TDS calculator adoted by the standard method for examination of water and waste water 20th edition (1999) when the calculated is used to test some solution like the ones used in these research work tends to fail as conductivity is a function of dissolve substance and depends on the valences of the various metal compounds that may be present in the water or waste water. Therefore from this work factors such as solubility of substances, ionization and valency causes a variatiuon in the ration of EC TO TDS in water samples as not all compounds are soluble in water, so insoluble substances in water samples will not affect TDS, also not all compounds can ionize in solutions or water samples only those that can ionize will effect EC. The valency of the metal compounds present in water samples affects the EC values as seen that the higher the valency, the higher the EC value.

Water samples must contain compounds that do not ionize in solution, compounds with different valencies and insoluble components. So it will not be correct to say that for water samples the EC and TDS are related by a particular difference, taking the factors above into considerations.

The model propose (although empirical) can help chemical and chemist like for to immediately obtain the TDS of a solution of metal compounds once the EC is known, this is helpful in the industrial and laboratories.

REFERENCES

[1] Atekwanaa, E.A, Atekwanaa, E.A, Roweb, R.S, Werkema D.D Jr. & Legalld, F.D. The relationship of total dissolved solids measurements to bulk electrical conductivity in an aquifer contaminated with hydrocarbon. *Journal of Applied Geophysics.* 56, 281–294, 2004.

[2] Wood, W.W. Guidelines for collection and field analyses of groundwater samples for selected unstable constituents. Techniques of Water-Resources Investigations of the United States Geological Survey, Book 1, Chapter D2. U.S. Geological Survey, Washington, DC. 1976.

[3] Lloyd, J.W. and Heathcote, J.A. (1985). Natural Inorganic Hydrochemistry in Relation to Groundwater, Clarendon Press, Oxford, England.

[4] Hem, J.D (1985). Study and Interpretation of the Chemical Characteristics of Natural Water, 3rd ed. U.S. Geological Survey Water-Supply Paper, vol. 2254. Washington, DC.

[5] www.lennetech.com

[6] DeZuane, J. *Handbook of Drinking Water Quality* (2nd ed.). John Wiley and Sons. 1997.

[7] www.smart-fretilizer.com.

[8] www.epa.gov/esd/cmb/pdf/JAG-TDSpublished.pdf.

[9] www.wikipedia.org

[10] Boyd, C.E. (1999). *Water Quality: An Introduction*. The Netherlands: Kluwer Academic Publishers Group. ISBN 0-7923-7853-9.

[11] Kaiser Engineers. California, *Final Report to the State of California, San Francisco Bay-Delta Water Quality Control Program*, State of California, Sacramento, CA. 1969.

[12] IAC Position Paper on Total Dissolved Solids, State of Iowa, IAC 567 61.3 (2) g et sequitur updated March 27, 2003

[13] Hogan, C.M, Patmore, L.C, and Seidman, H.(1973). "Statistical Prediction of Dynamic Thermal Equilibrium Temperatures using Standard Meteorological Data Bases". EPA-660/2-73-003. U.S. Environmental Protection Agency. Retrieved 2007-03-06

[14] Okuonghae, D.U. Mathematical modelling, Mathematics Department, University of Benin. (UNIBEN 2011).