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THE EFFECT OF COATING CONCENTRATION OF CURCUMIN:H_2O ON COPPER WINDING CHARACTERISTICS

Zainal Abidin
Corresponding author
Mechanical Engineering*
Department of Electrical Engineering
Universitas Islam Lamongan
Veteran str., 53 A, Jetis,
Lamongan, Indonesia, 62211
E-mail: zainal_fr@student.ub.ac.id
Eko Siswanto
Mechanical Engineering*
Widya Wijayanti
Mechanical Engineering*
Winarto
Mechanical Engineering*
E-mail: winarto@ub.ac.id
*Department Postgraduate Program
Brawijaya University
MT Haryono str., 167, Malang, Indonesia, 65145

Each coil of copper produces a magnetic field and the total field inside the solenoid will be the sum of the fields caused by each coil of current. If the solenoid coils are very closely spaced, the internal field will be essentially parallel to the axis except at the very ends. To find out the magnitude of the magnetic field inside the solenoid, you can use Ampere's law, namely $B=\mu o \cdot N \cdot I$, where B is the magnetic field strength (T), μo is air permeability (4×10^{-7} T m/A), N is the number of turns and I is an electric current. The value of B depends on the number of turns per unit length, N, and current I. The field is independent of the position inside the solenoid, so the value of B is uniform. This only applies to infinite solenoids, but is a good approximation for actual points that are not near the ends of the solenoid.

The research object is 4 identical copper coils with a length of 3 cm, a coil diameter of 2 cm, a cross section of 1.5 mm^2 with an inductance value of 2.17 μH. Before coating curcumin on the copper winding, the initial value of the magnetic field strength was 2.54 μTesla. After the coating process of curcumin: H_2O concentration, the value of the magnetic field strength increased.

The method used was immersing 4 copper coils with an inductance value of 2.17 μH in curcumin: H_2O concentration in a 100 ml volume measuring cup, with the respective concentrations: (20 %:80 %), (40 %:60 %), (60 %:40 %), (80 %:20 %) in a certain time. Then the copper coil conductor is supplied with a 5-volt DC voltage source. Then the value of the magnetic field strength (B) and electric current is measured, the results are compared with the system before immersing the copper coil.

The measurement results showed that the values of electric current and magnetic field strength increased after curcumin coating compared to before treatment. To see the bonding performance of curcumin and copper, the FTIR test and simulation of the curcumin: copper bond were carried out using Avogadro software. In the IR test, there is a strong absorption of aromatic C-C from 1,650 cm^{-1} to 1,500 cm^{-1}. Whereas in the simulation, the bond between copper and curcumin produces a bond energy of 164.532 kJ/mol or equivalent to 171.12×10^{-2} eV

Keywords: aromatic ring, electron spin, magnetic field, copper coil, curcumin concentration

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1. Introduction

In today's industry, the role of equipment that generates electromagnetic fields is in various equipment applications such as telecommunications, motors, generators, wireless power transfer, and others [1]. An electromagnet is a form of temporary magnet with magnetic properties in which a magnetic field is generated due to the presence of an electric current. The shape of the copper coil can be arranged in various forms, one form of copper winding is the solenoid [2, 3]. Solenoids are generally used in experimental research that requires a magnetic field. Each copper coil produces a magnetic field and the total field inside the solenoid will be the sum of the fields developed by each of the current coils. If the solenoid coils are very closely spaced, the internal field will be essentially parallel to the axis except at the very edges. To find out the magnitude of the magnetic field inside the solenoid, you can use Ampere's law, namely $B=\mu o \cdot N \cdot I$, where B is the magnetic field strength (T), μo is air permeability (4×10^{-7} T m/A), N is the number of turns and I is electric current. The value of B depends on the number of turns per unit length, N, and current I. The field is independent of the position inside the solenoid, so the value of B is uniform. This only applies to infinity solenoids, but is a good approximation for actual points that are not near the ends of the solenoid [4].

The electronic spin effect of two aromatic rings of curcumin on copper metal was studied. Some literature states that in curcumin's aromatic ring, phi electrons are spread evenly around the ring and each carbon is equivalent [5]. At the electrostatic potential of the curcumin aromatic benzene ring, the phi electrons are distributed evenly around the ring and each carbon is the same [6]. So as to produce induced energy and a magnetic field that is quite stable.

Curcumin is a polyphenolic pigment that gives turmeric its yellow color. The use of curcumin is related to the presence of a β-diketone group in its chemical structure. The role of curcumin as a complexing ligand is supported by the presence of a lone pair of electrons (lone pair electrons) from the β-diketone group, which can bind/entrap metals, thus forming a metal-curcumin complex [6]. One-electron oxidation of the two complexes by radiolytically generated azide radicals in Tx-100 micellar solutions produced phenoxyl radicals, indicating that the phenolic moiety of curcumin in the complexes participates in free radical reactions [7]. So that further study of this cluster is quite an interesting study to do. One of the physical properties possessed by metals is the property of electrical conductivity. Electrical conductivity is the ability of a material to conduct electric current [8]. The metal that people use is usually metal that is produced by factories and has been mixed with other materials, so that the metal is impure (commercial material). Electrical conductivity tells us how well a material will allow electricity to travel through it. Many people think of copper wires as something that has great electrical conductivity [9]. Testing the properties of electrical conductivity carried out on commercial metals will be an important parameter in determining the conductivity value of a material [10]. In addition, the selection of copper as an important metal in the use of electrical equipment in electric motors, transformers, generators and other supporting equipment is based on the electrical conductivity factor [10].

The experiment to be carried out on copper coils is to coat curcumin on copper coils in the hope of being able to produce a certain amount of electrons and energy with the aim of increasing the conductivity performance of copper conductors. The electric current flowing in the copper winding system, which was given a voltage source in the initial research, experienced a change in value at a certain concentration. As the electric current increases, so does the magnetic field strength.

The topic of research by utilizing the concentration of curcumin:H_2O in copper winding coating with the aim of obtaining changes in the characteristics of the copper winding is still relevant to do. Due to the influence of the aromatic ring on curcumin, it can improve the performance of the copper coil, especially increasing the value of electric current, magnetic field strength and increasing the conductivity of copper conductors.

2. Literature review and problem statement

Complexation of curcumin with metal at the β-diketone ligand site has been presented as an innovative and promising approach [8, 9]. The emission properties of curcumin as well as curcumin complexes with various metals such as magnesium, zinc, copper, and manganese have been reported, making the development of curcumin-based materials attractive and promising [10]. Cu(II)–curcumin interactions at different binding sites, including the diketo/keto-enol oxygen atom and the –OH phenolic group on ring A or B at the molecular level were studied [10]. For this purpose, chemical properties have been examined intrinsic of Cur, protonated [Cur+H]+ and [Cu(Cur–H)]+ and copper(II), respectively, which are envisioned as significant intermediates in relevant biomolecular mechanisms [11].

Cur-Nano consisting of 100 % aromatic substituted polymers showed the highest stability of curcumin (80 % residual curcumin) with the same particle size as measured on the first day (50–60 nm) in all storage conditions. The curcumin in Cur-Nano, which consists of 25 % and 0 % aromatic substituted polymers, is significantly less stable. The results indicated that the substitution of aromatics to HPMA-based polymer micelles could significantly improve the stability of the curcumin loaded, due to the π-π stacking interactions between the curcumin aromatic moieties and the polymer [12]. In the carbonyl group, a carbon atom is bonded to the more electronegative oxygen so that the electrons in the C=O bond are more attracted to the oxygen and this bond becomes polar. This effect is more pronounced for the less tightly conserved π electrons. [13]. It can be seen that the oxygen in the carbonyl group has two lone pairs of electrons. The presence of π bonds, polarity and lone electrons affect the reactivity of the carbonyl group [12].

As a result of the reaction between curcumin (CC) and copper(II), the characteristic peak of curcumin at –1.0 V increases significantly, and the peak at –1.6 V disappears. Curcumin forms a complex with copper (II). The interaction between double-stranded (ds) calf-thymic DNA and curcumin in the presence of Cu(II) was studied in solution, by differential pulse adsorptive transfer voltammetry using a carbon paste electrode (CPE) and a hanging mercury drop electrode (HMDE). The Cu(II)–CC complex produces changes in the calf-thymus DNA. The characteristic peak of dsDNA, due to the oxidation of guanine residues, decreases. Increased DNA damage by Cu(II)–CC complexes was observed in the presence of various concentrations of the transition metal ion, copper(II) [14].

The delocalization of the rings makes each of them count as one half bond between carbons, which makes sense because experimentally we found that the actual bond length is somewhere in between single and double bonds. Finally, there are a total of six electron *p*-orbitals that form a stabilizing electron cloud above and below the aromatic ring [15]. Aromaticity of benzene, the resulting molecule is planar in shape with each C-C bond being 1.39 Å in length and each bond angle being 120°. You might ask yourselves how it's possible to have all of the bonds to be the same length if the ring is conjugated with both single (1.47 Å) and double (1.34 Å), but it is important to note that there are no distinct single or double bonds within the benzene. The delocalization of the ring makes each count as one and a half bonds between the carbons, which makes sense because experimentally we found that the actual bond length is somewhere in between a single and double bond [16]. Finally, there are a total of six *p*-orbital electrons that form the stabilizing electron clouds above and below the aromatic ring [17]. This is a fundamental characteristic of all particles, not only electrons, and is analogous to the intrinsic spin of bodies elongated on their own axis, such as the Earth's daily rotation [18]. Spin is quantized in the same way as orbital angular momentum. Electrons are magnetic, therefore it is expected that electrons interact with other magnetic fields. The interaction of free electrons with an external (non-uniform) magnetic field and electrons in hydrogen atoms with a magnetic field is generated by the angular momentum of the electron orbitals [19]. In aromatic rings, there is an electron spin effect. Spin introduces two additional quantum numbers to our model of the hydrogen atom. Both are found by looking fine structure of the atomic spectrum. Spin is a fundamental characteristic of all particles, not just electrons, and is analogous to the intrinsic spin of a body extended about its own axis [20].

From Fig. 1 in step A, the electrophile reaction by aromatic pi bonds resulting in the C–E form breaking into

C–C (phi) can be seen. While in step B, deprotonation adjacent to the carbocation restores the aromaticity. So that C–H split, and form C–C (phi) and also (H–X). And the same thing can also happen to one of the six benzene carbons and produce the same product [21]. Electron-donating and electron-withdrawing substitution affect the nucleophilicity of the π bond (via pi donation and pi acceptance) as well as the stability of the intermediate carbocation, the logical conclusion being that attack on the electrophile is the rate-determining step [21]. Therefore, we have to depict it with a higher peak in the reaction energy diagram, which represents higher activation energy [22].

In Fig. 2, the bridge bond current $J_{B,pq}(t)$ is introduced, which is a specific case of an interatomic bond current, and is defined as the current bridging two aromatic rings P and Q, passing from the nearest neighbor carbon atom at site p to q. Here, each carbon atom Cp, or Cq belongs to a different aromatic ring P or Q, which are in the neighbors. The magnetic fields induced by the coherent π-electron ring currents are also estimated, and the position dependence of the magnetic fluxes is demonstrated [17].

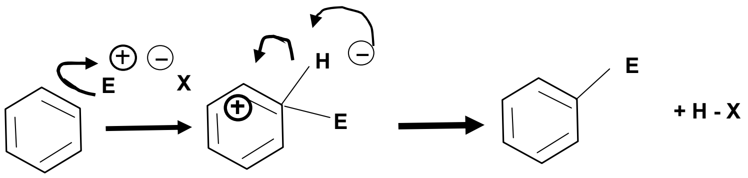


Fig. 1. General mechanism of aromatic electrophilic substitution

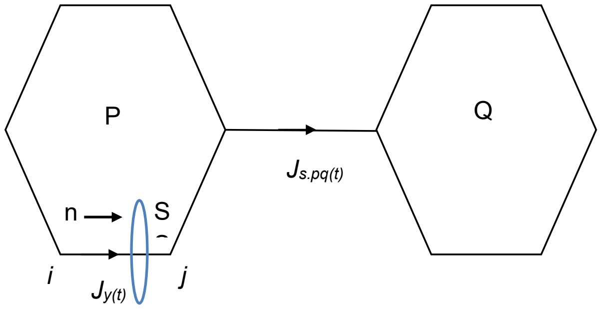


Fig. 2. The interatomic bond current $J_{ij}(t)$ and bridge bond current $J_{B,pq}(t)$ are depicted. Here, i and j indicate the positions of two atomic sites in the bond Ci–Cj, and each carbon atom Cp, or Cq belongs to a different aromatic ring P or Q, which are in neighbors [17]

Fig. 3 shows the bonding compounds of curcumin molecules with two symmetrical aromatic rings.

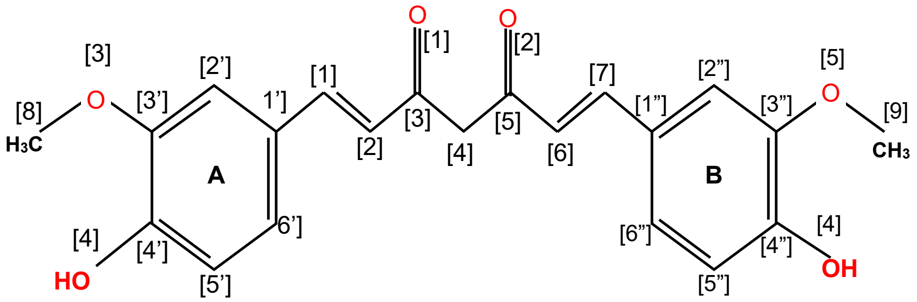


Fig. 3. Schematic curcumin representation [14]

From several literatures about the spin of the aromatic ring contained in curcumin compound particles, it has an influence on metals [23], especially copper. The formulation of the problem in this research is whether there is an effect of coating copper windings with curcumin: H_2O concentration on the value of magnetic field strength and electrical conductivity. The relationship between conductivity and resistivity can be described by the equation:

$$R=\rho x l/A, \tag{1}$$

$$\sigma=1/\rho, \tag{2}$$

where R – resistance (ohm), A – cross-sectional area (mm^2), l – coil length (cm), ρ – resistivity (Ω cm), σ – conductivity (Ω^{-1} cm^{-1}). From equations (1), (2) we get:

$$\sigma=1/\rho=1/(RA/l)=l/RA. \tag{3}$$

From the assumption that curcumin coating on the copper winding is expected to contribute to improving the conductivity of the conductor and in an effort to increase the strength of the magnetic field. From the initial research that we convey, it is very simple, to get a more in-depth study it really requires more specific attention with different models and methods.

Fundamentally, the equation of the magnetic field around the solenoid can be formulated:

$$B=\frac{\mu o\times N\times I}{L}, \tag{4}$$

where B – magnetic field strength (Tesla), μo – permeability of empty space, N – number of turns, I – electric current (A), and L – length of coil (m).

Curcumin as a carbon paste electrode coating acts as a complexing agent. Curcumin has O atoms in ketone groups as electron donors [12], which can form bonds with lead (II) metal ions, Pb^{2+}, forming Pb-curcumin complexes. The peak current in the measurement is the current that arises in the lead (II) oxidation process. Measurement of lead (II) by means of anode stripping voltammetry consists of two stages, namely the deposition stage and the stripping stage [13].

A new copper(II) complex from Knoevenagel curcumin condensate and Schiff base has been synthesized and characterized. All copper complexes have a distorted square planar geometry with a 1 to 1 metallic stoichiometry capable of stabilizing the Cu_{21}/Cu_{11} redox pair in the range of 0.34 to 0.40 V. The ESR spectral feature is consistent with $g_{\Downarrow} > g_{\perp} > 2.0$ and indicates the nature of the copper complex monomer having $d_{x^2-y^2}$ ground state [12].

Under conditions>pH 8, the enolate form of the heptadieno-dione chain predominates and curcumin exhibits chelatic properties towards ketones such as Fe^{3+}, Fe^{2+}, Cu^{2+}, Cd^{2+} and Ni^{2+}, the enolate form of curcumin, which acts as an electron donor and can coordinate well [13]. Curcumin can also protect against lead- and cadmium-induced lipid peroxidation and lead-induced tissue damage in rat brains or can participate in chelating iron ions which, in turn, take part in oxygen transfer [12].

Several curcumin complexes with copper and manganese have been studied for their superoxide dismutase (SOD) activity, free radical scavenging abilities and antioxidant potential. In the case of copper(II) complexes, distorted orthorhombic 1:1 Cu(Curc)(OAc)(OH)(OAc=acetate) complexes and 1:2 homoleptic complexes of $Cu(Curc)^2$ complex have been investigated [14].

The modified electrodes were characterized by square wave voltammetry (SWV), cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS). The sensitivity of the PdNp/GE and Al^{3+}/PdNp/GE electrodes was tested with dopamine [15]. Al^{3+}/PdNp/GE exhibits catalytic activity for curcumin oxidation. Square-wave voltammogram of curcumin in phosphate buffer (pH=2) gives an anodic peak at 0.56 V [16]. The anodic peak current of curcumin was found to be linearly related to its concentration in the range 3.0×10^{-8} M to 6.0×10^{-7} M with a detection limit of $2.2\ 10^{-8}$ M. It was also found that the novel Al^{3+}/PdNp/GE electrode had the best sensitivity when compared to glassy carbon (GCE) electrodes [17].

A linear relationship between the anodic peak current and curcumin concentration was observed between 0.325 µM to 1.95 µM at the EPPG electrode by differential pulse voltammetry. The limit of detection was calculated as 0.296 µM and this method was successfully applied to detect the amount of curcumin in turmeric samples [18].

Curcumin is a polyphenolic compound with the chemical formula $C_{21}H_{20}O_6$. Curcumin is a compound in the form of a crystalline powder with a melting point of 183 °C, reddish-yellow in color. Curcumin is insoluble in water and ether, soluble in alcohol and glacial acetic acid. The official name for curcumin is 1,7-Bis(4-hydroxy-3-methoxyphenyl)-1,6-heptadiene-3,5-dione. This compound is brownish-red in alkaline conditions and light yellow in acidic conditions [19].

Judging from its chemical structure, curcumin has the potential to be a chelating agent because it has a free electron structure and allows it to bind heavy metals [20]. Curcumin has a β-diketone group in its chemical structure. The O atoms in these groups have a lone pair of electrons. Ligands are substances that have one or more lone pairs of electrons and can act as electron donors in the formation of complex compounds with metal ions [21]. Ligands have groups that can be used to interact with metal ions. In relation to the chemical structure of curcumin, it is possible for curcumin to act as a complexing ligand that can trap/bind metal ions [22].

The lead (II) peak current response was given by curcumin-modified carbon paste electrodes at −0.493V vs. Ag/AgCl (saturated KCl). The best electrode composition is the ratio of graphite: paraffin oil: curcumin=3:2:5, where lead (II) can be measured on the ppb scale by differential pulse voltammetry. Optimum conditions for measurement were obtained at acetate buffer pH 4, deposition time of 60 seconds, and scan speed of 10 mV/second. The linear concentration area was obtained in the concentration range of 4.995–49.504 ppb with a detection limit of 1.3438±0.0096 ppb and R^2=0.9966. The interference from copper (II) and cadmium (II) affects the peak current of lead (II) by 59.60 % and 56.74 % respectively [22]. The interaction of curcumin with copper reaches a half maximum at ~3–12 µM copper and shows positive cooperativity, with $Kd1$~10–60 µM and $Kd2$~1.3 µM (for binding of the first and second curcumin molecules) [23].

The investigation of aromaticity in even larger molecular rings is interesting because ring currents are also observed when mesoscopic metal rings are placed in a magnetic field at low temperatures. The striking similarity between the ring currents in molecules and mesoscopic metal rings arises because the effects have a common origin: a field-dependent phase shift in the electronic wave function [23]. The main difference is that the magnetic flux through mesoscopic rings is much greater because of their larger areas [24], so their persistent currents are nonlinear and oscillatory with the applied field, whereas the flux through aromatic molecules is so small that their response is approximately linear in the applied field. We discuss how nonlinearity is expected to emerge in large molecular nanorings at high magnetic fields [25].

All this allows us to assert that it is prudent to carry out a study on the effect of curcumin:H_2O concentration on the characteristics of the copper coil.

3. The aim and objectives of the study

The aim of the study is to determine the effect of coating concentration of curcumin:H_2O on copper windings. This will make it possible to influence the characteristics of the copper winding given the voltage source, especially the increase in the value of the electric current, the increase in the magnetic field strength and the conductivity quality of the copper conductor.

To achieve this aim, the following objectives are accomplished:

– to conduct experiments on immersing copper coils in several concentrations of curcumin:H_2O for a certain time;

– to measure the magnetic field strength with a Gauss meter around a copper coil and test an electric current on a copper coil that is given an electric voltage of 5 vdc;

– to calculate the conductivity value of the conductor from the results of measuring the electric current;

– to conduct FTIR tests to obtain the characteristics of the elements present in curcumin and copper bonds;

– to simulate the curcumin:copper bond with Avogadro's simulation and analyze and interpret measurement and test results.

4. Materials and methods

The research object is the characteristics of copper coils, the characteristics in question are: conductor conductivity, electric current and magnetic field strength when the copper coil is given a voltage source.

The main hypothesis of the study: There is an effect of the concentration of curcumin:H_2O on the characteristics of the copper coil, which is given a voltage source, it can change the conductivity value of the conductor, affect the value of the electric current and increase the magnetic field strength.

Materials consist of 4 coils of 2.17 µH copper, 4 measuring cups of 100 ml volume filled with turmeric juice containing curcumin and distilled water (H_2O) with a ratio of 20 %:80 %, 40 %:60 %, 60 %:40 % and 80 %:20 %.

Initially, 4 coils are given a DC electric voltage of 5 volts, electric current and magnetic field strength are measured in the coils, after that 4 coils are put into each measuring cup with a mixture of curcumin:H_2O with a volume of 100 ml with a concentration of 8:80 p.m., 40:60 a.m., 60:40 a.m. and 80:20 a.m. Winding immersion time is from 0 to 4 hours. After the immersion time, measurements of the electric current and magnetic field strength in the windings are carried out (Fig. 5).

To strengthen the analysis of measurement results, infrared tests and bond modeling with Avogadro software, and analysis of measurement and material test results were carried out.

Fig. 4, 5 is the research planning design in the experiment laboratory.

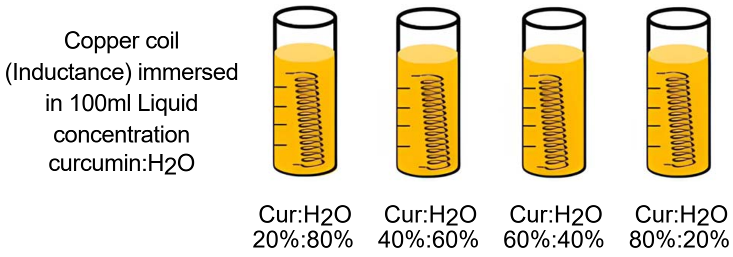


Fig. 4. The process of soaking coils in measuring cups with various concentrations (*experiment laboratory*)

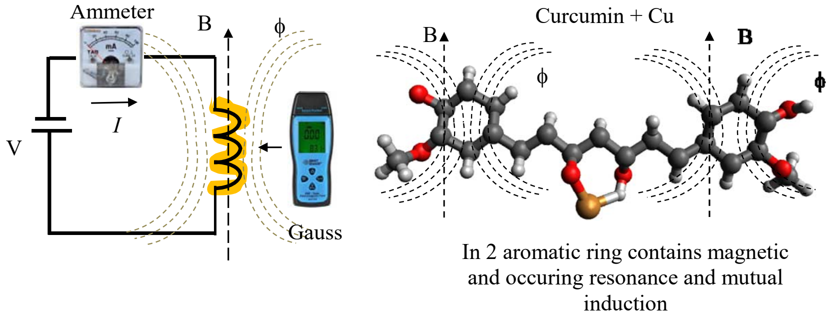


Fig. 5. Measurement model and curcumin bonding model:Copper (Cu) (*experiment laboratory*)

Fig. 5 shows that in the copper coil, a magnetic field is produced, as well as in the aromatic ring magnetic induction is produced.

The research object was 4 identical copper coils with an inductance value of 2.54 µH, which were coated with a concentration of curcumin:H_2O to determine the characteristics of the effect on increasing the magnetic field strength, current strength and conductivity values.

Research hypotheses: curcumin has two aromatic benzene rings, which contain a magnetic field that resonates, which can affect the electromagnetic field generated by a current of copper coils, the electromagnetic field in the coils is an independent variable, which is influenced by curcumin concentration and time as the dependent variable, so that at a certain concentration of curcumin and coating time it will increase the magnetic field strength in the copper coil.

The research assumption is based on experimental results that the greater the concentration of curcumin:H_2O, the value of electric current, magnetic field strength and electrical conductivity will increase.

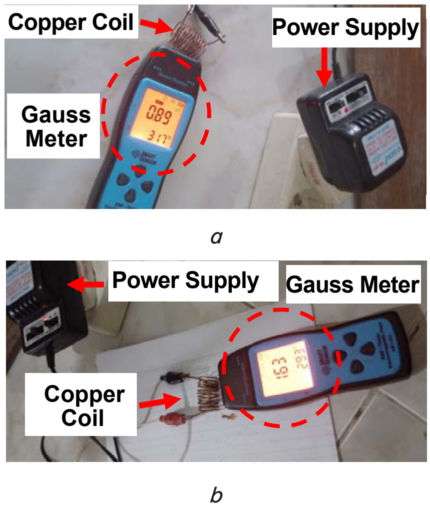
Practical method I chosen in this study is a simple method to prove that the concentration of curcumin :H_2O has an effect on changes in electric current, magnetic field strength and electrical conductivity in copper coils. The greater the concentration of curcumin:H_2O indicates that the electron donation of the aromatic ring to curcumin will increase.

5. Results of research on the effect of curcumin:H_2O concentration on the characteristics of copper coils

5. 1. Results of the coating process of curcumin:H_2O concentration on the copper coil

The process begins by preparing liquid curcumin from turmeric through a filtering process of 200 ml, then preparing 200 ml of distilled water (H_2O), then a mixture of curcumin concentration:H_2O is made with the composition: 20 %:80 %, 40 %:60 %, 60 %:40 % and 80 %:20 % each placed in a measuring cup with a volume of 100 ml. 4 turns of the identical coil with an inductance of 2.54 µH each is put in a measuring cup with a predetermined concentration.

At the next stage, during the immersion period of the coil winding for 0–4.5 hours, every 0.5 hours the coil winding is given a voltage of 5 vdc, and the results of measuring the magnetic field strength and electric current are recorded in Tables 1, 2, respectively.



a

b

Fig. 6. Measurement of magnetic field strength with a Gauss meter:
a – before coating curcumin on copper coil;
b – measurements after curcumin coating

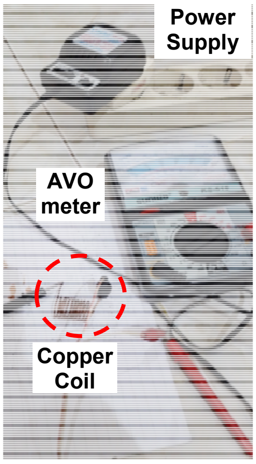


Fig. 7. Measurement of electric current

5. 2. Results of measuring magnetic field and electrical current test

An experiment was carried out by immersing 4 pieces of copper coils with the same value of 2.54 µH into a measuring cup with a volume of 100 ml with the concentration of curcumin:H_2O. From the immersion, the values of the magnetic field strength and electric current were measured as presented in Tables 1, 2 below.

Table 1

Magnetic field strength values in copper winding coatings with various concentrations of curcumin:H_2O

Time (hours)	Magnetic field strength value (B) of the copper winding (mTesla)			
	20:80	40:60	60:40	80:20
0.50	2.54	2.54	2.54	2.54
1.00	2.65	2.65	2.75	2.75
1.50	2.70	2.70	2.90	3.00
2.00	2.87	2.87	3.30	3.40
2.50	3.30	3.30	4.14	4.30
3.00	3.34	3.34	4.20	4.50
3.50	3.55	3.65	4.25	5.44
4.00	4.20	4.30	4.90	6.43
4.50	4.30	4.45	5.20	6.75

Table 2

Electric current values in copper winding coating with various concentrations of curcumin:H_2O

Time (hours)	Electric current value (mA) of the copper winding in some curcumin: H_2O compositions			
	20:80	40:60	60:40	80:20
0.50	0.72	0.72	0.73	0.73
1.00	0.73	0.73	0.73	0.74
1.50	0.73	0.73	0.73	0.74
2.00	0.75	0.75	0.76	0.77
2.50	0.75	0.75	0.81	0.81
3.00	0.81	0.82	0.82	0.82
3.50	0.81	0.82	0.83	0.84
4.00	0.82	0.82	0.86	0.86
4.50	0.83	0.84	0.95	1.10

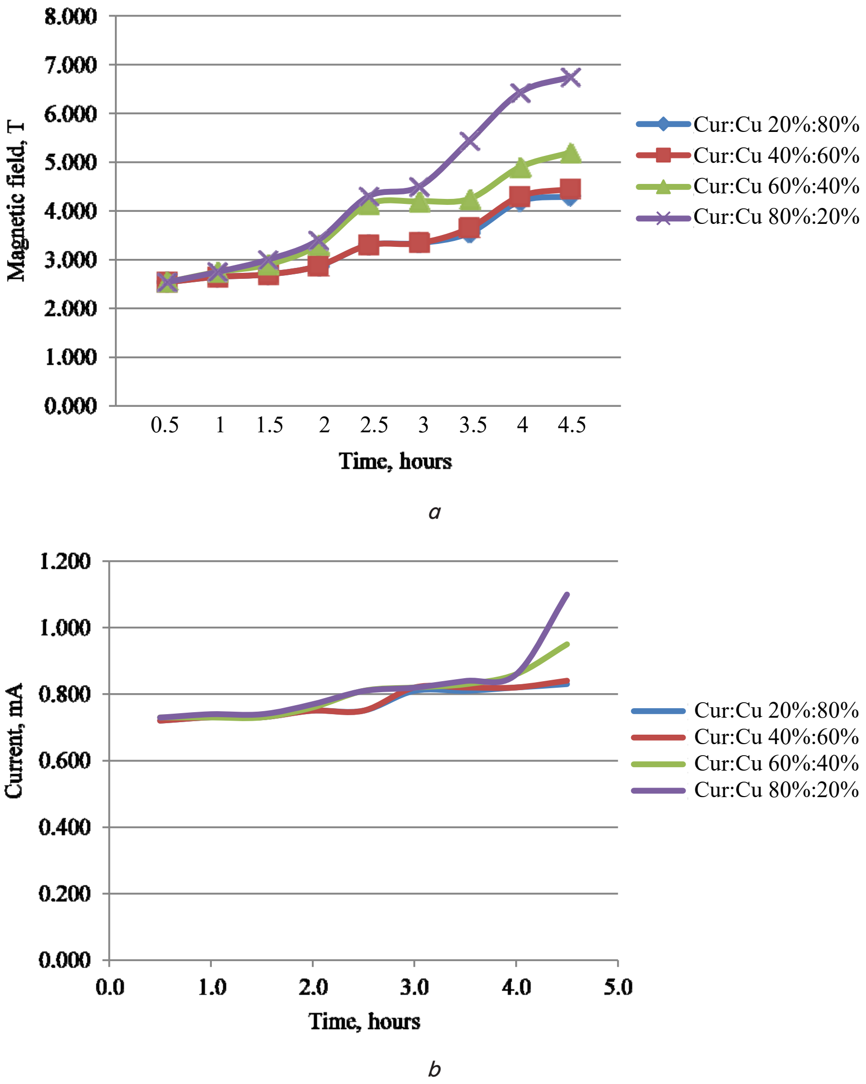


Fig. 8. The main signature: *a* – graph of changes in magnetic field strength (B); *b* – the value of changes in electric current at various concentrations of curcumin: H_2O

As can be seen from Table 1, the initial value of the magnetic field strength for the 4 windings was measured at 2.54 μT, the value of the magnetic field strength of the windings experienced the highest increase in immersion for 4.5 hours. For the concentration curcumin: H_2O (20:80), it increased by 4.30 μT (69.29 %), for the concentration (40:60) increased by 4.45 μT (75.20 %), for the concentration (60:40) increased by 5.20 μT (104.72 %) and for the 80:40 concentration increased by 6.75 μT (165.75 %). Meanwhile, Table 2 shows the increase in the value of electric current at several concentrations of curcumin:H_2O. The table indicates the highest increase in current in the composition of curcumin: H_2O with a percentage of 80:20, which is 1.1 A (52.77 %). The graph of the relationship between changes in magnetic field strength and electric current can be depicted in Fig. 8, *a*, *b*, respectively.

5. 3. Calculation of copper coil conductivity values in the coating process of curcumin: H_2O concentrations

Meanwhile, as can be seen from (4) and (5), the resistance and electrical conductivity of the copper winding are shown in Tables 3, 4, respectively.

Table 4 can be described in Fig. 9 below.

Table 3

Resistance values in copper winding coating with various concentrations of curcumin: H_2O

Time (hours)	Resistance (ohm) of the copper winding at some concentrations of curcumin:H_2O			
	20:80	40:60	60:40	80:20
0.50	6.94	6.94	6.85	6.85
1.00	6.85	6.85	6.85	6.76
1.50	6.85	6.85	6.85	6.76
2.00	6.67	6.67	6.58	6.49
2.50	6.67	6.67	6.17	6.17
3.00	6.17	6.10	6.10	6.10
3.50	6.17	6.10	6.02	5.95
4.00	6.10	6.10	5.81	5.81
4.50	6.02	5.95	5.26	4.55

Table 4

Conductivity values in coating copper windings with various concentrations of curcumin: H_2O

Time (hours)	Conductivity value ($ohm^{-1}cm^{-1}$) of the copper winding at some concentrations of curcumin:H_2O			
	20:80	40:60	60:40	80:20
0.50	28.80	28.80	29.20	29.20
1.00	29.20	29.20	29.20	29.60
1.50	29.20	29.20	29.20	29.60
2.00	30.00	30.00	30.40	30.80
2.50	30.00	30.00	32.40	32.40
3.00	32.40	32.80	32.80	32.80
3.50	32.40	32.80	33.20	33.60
4.00	32.80	32.80	34.40	34.40
4.50	33.20	33.60	38.00	44.00

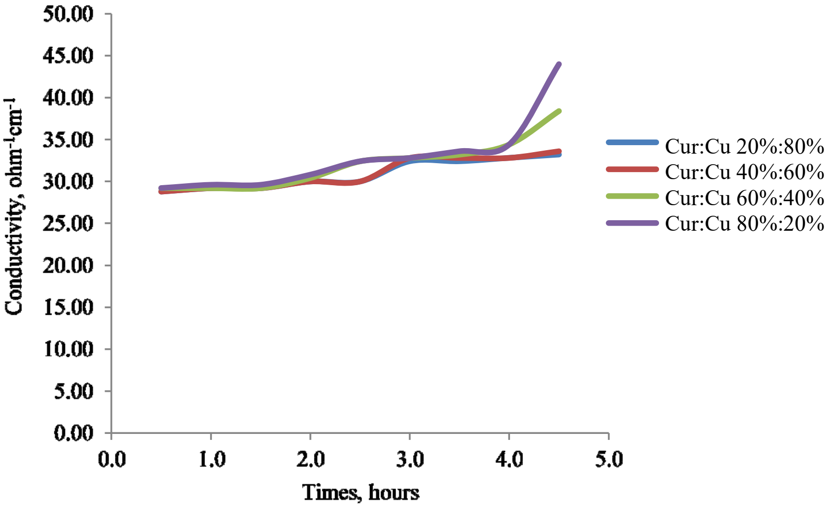


Fig. 9. Electrical conductivity of copper windings at various coating concentrations of curcumin:H_2O

From Table 4, it is conveyed that the concentration level of curcumin: H_2O affects the increase in the conductivity value of copper. The increase was greatest when the concentration of curcumin:H_2O was at (80 %:20 %) level.

5. 4. Results of Fourier transfer infrared

Gained from the FTIR test, the IR spectra of curcumin and copper powder (curcumin: Cu) were obtained as shown in Fig. 10 below.

Fig. 10 shows the infrared spectra of the FTIR test of copper powder and curcumin, the absorption broadening at a wavelength of 3,250 cm^{-1} is the O–H absorption of alcohol. Strong absorption at a wavelength of 2,900 cm^{-1} is an alkane C–H absorption.

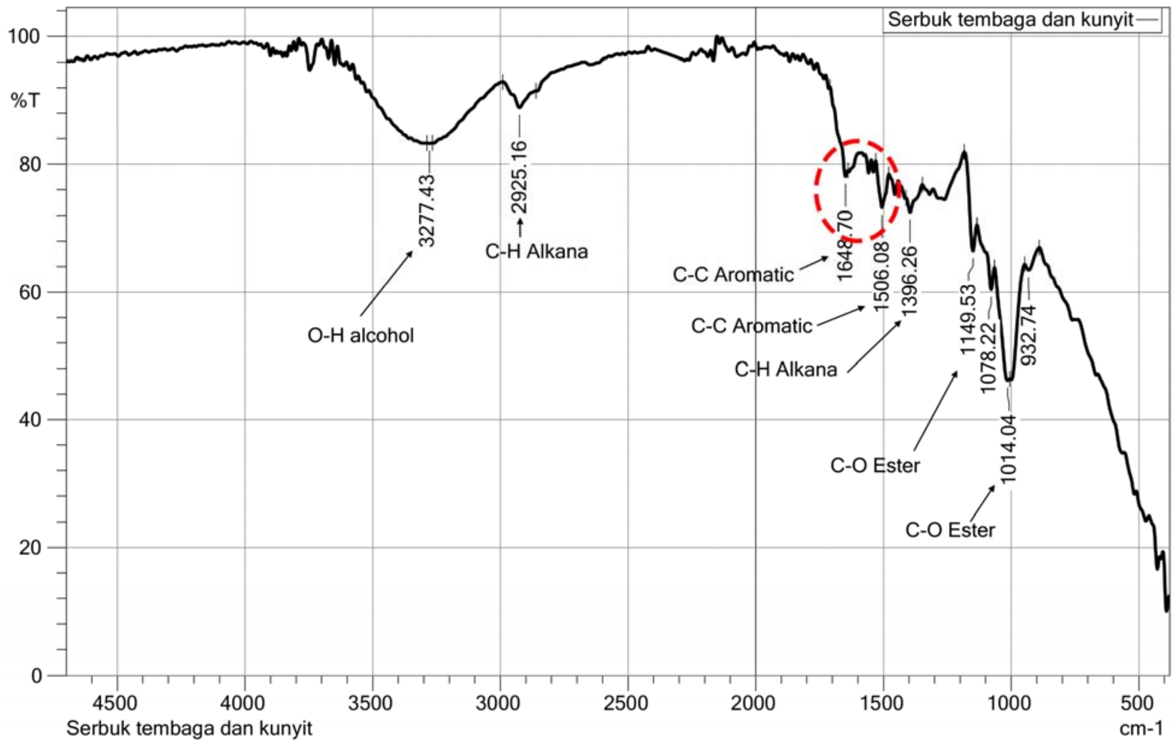


Fig. 10. Infrared spectra of copper and curcumin

At wavelengths from 1,650 cm^{-1} to 1,500 cm^{-1} there is a strong absorption of aromatic C–C. At a wavelength of 1,200 cm^{-1} to 1,000 cm^{-1} there is a strong and sharp absorption from the C–O ester and at a wavelength of 932 cm^{-1} there is a moderate absorption from the C–H Alkene. The IR spectra test showed the presence of aromatic C–C groups at a wavelength of 1,650 cm^{-1} to 1,500 cm^{-1}.

5. 5. Results of simulation of the copper-curcumin bond

Fig. 11 presents the results of the Avogadro software simulation, where the Cu:Curcumin ($C_{21}H_{20}O_6$) bond with the simulation results of bond properties is shown in Table 5.

From Table 5, the curcumin and copper bonds have a wavelength of around 1.52387 – 1.8972 Angstrom (1.52387×10^{-8}–1.8972×10^{-8} cm).

From the results of experiments, measurements and simulations, it is shown that there was a change in the performance of the copper winding after the curcumin concentration coating process was carried out as described. These changes in performance values are due to electromechanisms occurring in the curcumin aromatic ring, which affect the electromagnetic characteristics of the copper coils.

The general mechanism of the electron release process in the aromatic ring of the curcumin molecule is presented in Fig. 12 [21].

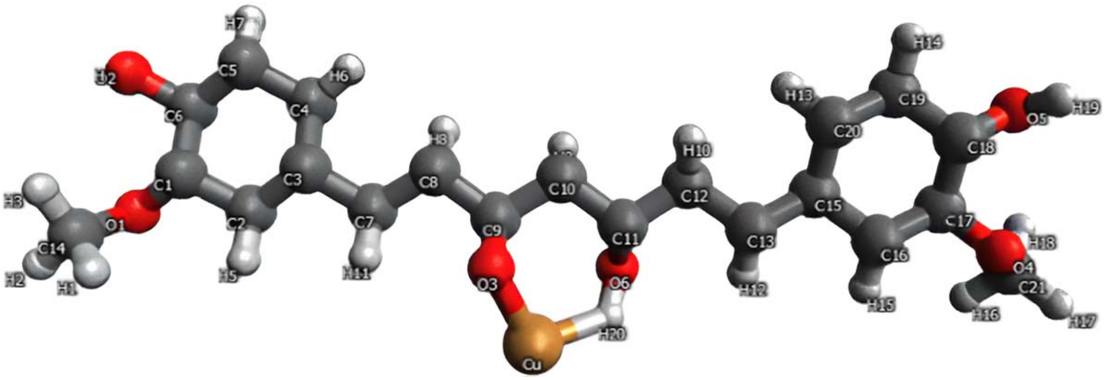


Fig. 11. The curcumin-copper bond model

Table 5

Properties of the curcumin-copper bond

Bond	Type	Start Atom	End Atom	Bond Order	Rotatable	Length(A)
1	2	3	4	5	6	7
Bond 1	C-C	C1	C2	1	Yes	1.52387
Bond 2	C-C	C3	C2	1	Yes	1.53136
Bond 3	C-C	C4	C3	1	Yes	1.53645
Bond 4	C-C	C5	C4	1	Yes	1.52634
Bond 5	C-C	C6	C5	1	Yes	1.52605
Bond 6	C-C	C6	C1	1	Yes	1.52992
Bond 7	C-C	C7	C3	1	Yes	1.53567
Bond 8	C-C	C8	C7	1	Yes	1.52656
Bond 9	C-C	C9	C8	1	Yes	1.52526
Bond 10	C-C	C10	C9	1	Yes	1.52688
Bond 11	C-C	C11	C10	1	Yes	1.52968
Bond 12	C-C	C12	C11	1	Yes	1.52547
Bond 13	C-C	C13	C12	1	Yes	1.52638
Bond 14	O-C	O1	C1	1	Yes	1.40407
Bond 15	O-C	O2	C6	1	No	1.39642
Bond 16	H-O	H4	O2	1	No	0.99040
Bond 17	O-C	O3	C9	1	Yes	1.38730
Bond 18	O-C	O4	C11	1	No	1.39893
Bond 19	H-C	H8	C8	1	No	1.11086
Bond 20	H-C	H9	C10	1	No	1.11219
Bond 21	H-C	H10	C12	1	No	1.11117
Bond 22	H-C	H11	C7	1	No	1.11197
Bond 23	H-C	H5	C2	1	No	1.11106

Continuation of Table 5

1	2	3	4	5	6	7
Bond 24	H-C	H7	C7	1	No	1.11078
Bond 25	H-C	H6	C4	1	No	1.10952
Bond 26	H-C	H12	C13	1	No	1.11191
Bond 27	H-O	H13	O4	1	No	1.09363
Bond 28	C-O	C14	O1	1	No	1.40475
Bond 29	H-C	H1	C14	1	No	1.11395
Bond 30	H-C	H2	C14	1	No	1.10937
Bond 31	H-C	H3	C14	1	No	1.11235
Bond 32	C-C	C15	C20	1	Yes	1.53641
Bond 33	C-C	C20	C19	1	Yes	1.52573
Bond 34	C-C	C19	C18	1	Yes	1.52573
Bond 35	C-C	C18	C17	1	Yes	1.52684
Bond 36	C-C	C17	C16	1	Yes	1.53005
Bond 37	C-C	C16	C15	1	Yes	1.52861
Bond 38	C-C	C13	C15	1	Yes	1.53149
Bond 39	H-C	H17	C21	1	No	1.53607
Bond 40	H-C	H18	C21	1	No	1.11413
Bond 41	H-C	H19	C21	1	No	1.10953
Bond 42	C-O	C21	O5	1	No	1.11214
Bond 43	O-C	O5	C17	1	Yes	1.40463
Bond 44	H-C	H16	C16	1	No	1.40468
Bond 45	H-C	H14	C20	1	No	1.11114
Bond 46	H-C	H15	C19	1	No	1.10971
Bond 47	O-H	O6	H20	1	No	1.11077
Bond 48	O-C	O6	C18	1	No	0.990543
Bond 49	Cu-H	Cu	H13	1	No	1.76881
Bond 50	O-Cu	O3	Cu	1	No	1.8972

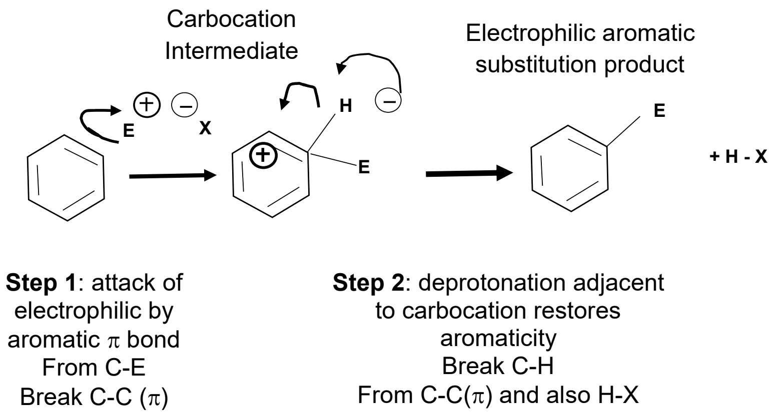


Fig. 12. The general mechanism of the electron release process in the aromatic ring: *a* – attack of electrophile by aromatic phi bond; *b* – depronotation adjacent to carbocation restores aromaticity [21]

The reaction energy diagram can be seen in Fig 13 below.

The external magnetic field interacts with the electrons of the molecule by inducing a current [22]. This magnetically induced current is useful as a measure of aromaticity [26].

By inducing a magnetic field in the description of quantum chemistry, the magnetically induced current density of a molecule can be calculated and processed to produce a quantitative measure of aromaticity [27].

The induced current creates a secondary magnetic field B, as depicted in Fig. 14, *a*. The relationship between the secondary magnetic field and current is given by Biot Savart's law [20]:

$$B=\frac{\mu o}{4\pi}\int\frac{r\,xJ^{B}(r)}{r^{3}}\mathrm{d}r, \qquad (5)$$

where B – magnetic field, J^{B} – induction current density.

The induced magnetic field can weaken or strengthen the applied field, called the shielding or deshielding effect, respectively [20, 28]. In aromatic compounds, the diatropic ring current induces a magnetic field that shields the inside of the ring and detaches the outside, and the paratropic ring current has the opposite effect. The benzene-induced magnetic field is shown in Fig. 14 [26].

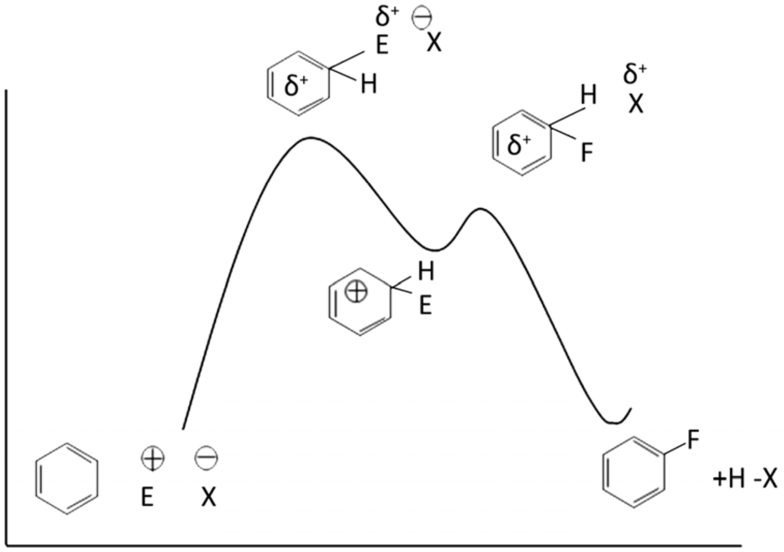


Fig. 13. Reaction energy diagram in electrophilic aromatic substitution [21]

The induced magnetic field is related to Bext's applied magnetic field via the shielding tensor [20]

$$\mathbf{s}B_{locks}=-\mathbf{s}B_{ext}. \tag{6}$$

As long as the curcumin-coated copper wire has a field strength B_1, while the curcumin layer attached to the copper also produces a magnetic field strength (B_2) along the wire, so the assumption of the field strength that occurs is $B=B_1+B_2$ so the equation became:

$$B=\frac{\mu o\cdot I}{2\pi r}+\frac{\mu o}{4\pi}\int\frac{rxJB(r)}{r^3}. \tag{7}$$

From equation, it followed that testing copper windings coated with curcumin increases the magnetic field strength.

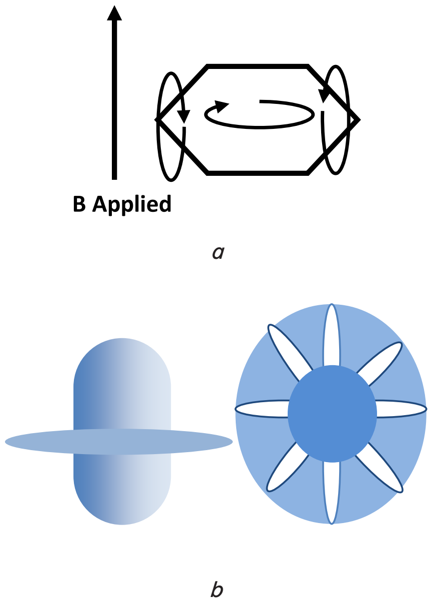


Fig. 14. Magnetic shielding: *a* — schematic illustration of a secondary magnetic field induced by a magnetically induced ring current; *b* — an induced benzene magnetic field. Blue denotes areas of magnetic shielding [26]

6. Discussion of experimental results of research on the effect of curcumin:H_2O concentration on the characteristics of copper coils

Based on formula (4), referring to the results of Tables 1, 2, the relationship between the strength of the magnetic field (B) and electric current (I) is shown where the greater the electric current, the stronger the magnetic field also increases.

From equation (3), referring to Tables 3, 4 it is shown that if the resistance value is getting smaller, the conductivity value is increasing.

From Fig. 13, it is shown that there is an energy reaction from the aromatic ring in the curcumin:Cu bond, which results in electron donation to copper. The presence of phenolic functional groups and double bonds allows oxidation and reduction reactions to occur in these groups. Curcumin is known to have the ability to donate electrons [24]. Table 1 explains that there is an increase in the magnetic field strength (B) at the concentration of curcumin: H_2O (80 %:20 %), this is due to an increase in electric current in the copper winding loop system so that the magnetic field strength also increases in value. The increase in electric current is due to the donation of electrons from the curcumin aromatic ring, which forms a shielding magnet, which also results in magnetic induction [26].

The independent variable in this study was the effect of the concentration of curcumin:H_2O on the copper winding coating, while the dependent variable was the characteristics of the electric current, magnetic field strength and conductivity of the conductor. However, the most important element is that the electric current increases, so that the value of the magnetic field strength B and the conductivity of the conductor σ also increase.

Table 6 shows several methods used in the research of curcumin compounds with metals, especially copper. Of the several methods used in this research, the use of curcumin with Cu(I), Cu^{2+}, with IR testing, SEM, TEM, and others. While my research uses curcumin and Cu from copper windings by measuring the magnetic field directly that have been coated with a concentration of curcumin:H_2O, which is given an electric voltage source. For the IR performance test, FTIR and the Avogadro application were used to determine the bonding properties of curcumin and copper.

This research is still very simple, because the sample used is also very simple. With a small copper coil, the voltage used is also small. However, the significant changes in the values of I, B and σ are a model that can be developed further. The weakness of this study is that it still uses a very simple method, and of course, there are still many shortcomings in describing the results. In future research, a more comprehensive method is needed so that errors can be reduced.

The development of this research is the use of curcumin in wireless power transfer systems with the aim of increasing the electric current in the two windings, namely the transmitter and receiver, increasing mutual inductance and also possibly increasing the transmission range.

Table 6

Research method for curcumin and metal chelating

Topic of research	Method	Reference
1	2	3
Synthesis of Metal-Curcumin Complex Compounds (*M*=Na^+, Mg^{2+}, Cu^{2+})	Curcumin (86 mg, 0.234 mmol) was dissolved in 30 mL ethanol mixed with solid NaOH (9 mg, 0.234 mmol), then reacted with the metal precursor $CuC1_2.2H_20$ (20 mg, 0.117 mmol). The solids of the reaction product were purified through separation using column chromatography using 60 silica gel (230–400 mesh) stationary phase and dichloromethane mobile phase	[6]
Comparative study of copper (II) e curcumin complexes as superoxide dismutase mimics and free radical scavengers	Two stoichiometrically different copper(II) complexes of curcumin (stoichiometry, 1:1 and 1:2 for copper:curcumin) were examined for their superoxide dismutase (SOD) activity, free radical-scavenging ability and antioxidant potential. Both complexes are soluble in lipids and DMSO. The formation constants of the complexes were determined by voltammetry. EPR spectra of the complexes in DMSO at 77 K showed that the 1:2 Cu(II)ecurcumin complex is square planar and the 1:1 Cu(II)ecurcumin complex is distorted orthorhombic. Cu(II)ecurcumin complex (1:1) with larger distortion from square planar structure shows higher SOD activity	[7]
Full Structural Characterization of Homoleptic Complexes of Diacetylcurcumin with Mg, Zn, Cu, and Mn: Cisplatin-level Cytotoxicity in Vitro with Minimal Acute Toxicity in Vivo	Compound Curcumin+Copper was characterized by ultraviolet-visible (UV-Vis), fluorescence spectroscopy, infrared spectroscopy (IR), liquid and solid-state nuclear magnetic resonance (NMR), electron paramagnetic resonance (EPR), magnetic moment, mass spectrometry (MS), single crystal, and powder X-ray diffraction (SCXRD and PXRD)	[11]
Interaction of curcumin with Zn(II) and Cu(II) ions based on experiment and theoretical calculation	Curcumin and its complexes with Zn^{2+} and Cu^{2+} ions were synthesized and characterized by elemental analysis, mass spectroscopy, IR spectroscopy, UV spectroscopy, solution 1H and solid-state 13C NMR spectroscopy, EPR spectroscopy. In addition, the density functional theory (DFT)-based UV and 13C chemical shift calculations were also performed to view insight into those compound structures and properties	[31]
DNA interaction studies of a novel Cu(II) complex as an intercalator containing curcumin and bathophenanthroline ligands	A new copper(II) complex; [Cu(Cur)(DIP)]+2 in which Cur – curcumin and DIP – 4,7-diphenyl-1,10-phenanthroline was synthesized and characterized using different physico-chemical methods. Binding interaction of this complex with calf thymus (CT-DNA) has been investigated by emission, absorption, circular dichroism, viscosity, and differential pulse voltammetry and fluorescence techniques	[32]
Electroanalytical study of the interaction between dsDNA and curcumin in the presence of copper(II)	The interaction between double stranded (ds) calf-thymus DNA and curcumin in the presence of Cu(II) was studied in solution by differential pulse adsorptive transfer voltammetry using a carbon paste electrode (CPE) and hanging mercury drop electrode (HMDE). Cu(II)–CC complex generated changes in calf-thymus DNA. The characteristic peak of dsDNA, due to the oxidation of guanine residues, decreased	[33]
Curcumin based supramolecular ensemble for optical detection of Cu^{2+} and Hg^{2+} ions	The structure of the probe L1 was characterized by UVeVis, Fluorescence, SEM, PXRD and other related spectroscopic techniques. The molecular probe L1 was screened over assorted metal ion and selectivity was observed with Cu^{2+} and Hg^{2+} ions through the change of color in aqueous medium, which was confirmed by UV or fluorescence signal and also supported by SEM and PXRD results	[34]
Synthesis, characterization, electrochemical behavior and antioxidant activity of new copper(II) coordination compounds with curcumin derivatives	The complexes were characterized by elemental and thermogravimetric analysis, IR, UV–Vis and mass spectroscopic methods and cyclic voltammetric studies	[35]
Interaction of curcumin with Zn(II) and Cu(II) ions based on experiment and theoretical calculation	Curcumin and its complexes with Zn^{2+} and Cu^{2+} ions were synthesized and characterized by elemental analysis, mass spectroscopy, IR spectroscopy, UV spectroscopy, solution 1H and solid-state 13C NMR spectroscopy, EPR spectroscopy. In addition, the density functional theory (DFT)-based UV and 13C chemical shift calculations were also performed to view insight into those compound structures and properties	[36]
Preparation and Characterization of Curcumin functionalized copper 5 nanoparticles and their application enhances disease resistance in chickpea against wilt pathogen	The present study aims to prepare curcumin copper nanoparticles (Cur-CuNPs) to improve its aqueous solubility to use as an antifungal agent and to protect chickpea plants from the devastating pathogen, *Fusarium oxysporum* f. sp. *ciceri* (FOC). The Cur-CuNPs were analyzed by 1H NMR, 13C NMR spectroscopy. The structure, size and morphology were characterized through FTIR, SEM, TEM and XRD analyses	[37]
Effects of Cu(II) and Zn(II) coordination on the trypanocidal activities of curcuminoid-based ligands	Four heteroleptic metal complexes with the general formula [M(L1-2)(phen)Cl] 1a-b, 2ab, (*M*=Cu(II) or Zn(II), L – curcuminoid ligand and phen – phenanthroline) have been prepared from the reaction of the ligands in the presence of Et3N with $CuCl_2.2H_2O$ or $ZnCl_2$. Characterization by IR, 1H NMR and EPR spectroscopies, and X-ray diffraction analysis for 1b confirmed the proposed structures for the complexes	[38]

Continuation of Table 6

Spectroscopy driven DFT computation for a structure of the monomeric Cu^{2+}-Curcumin complex and thermodynamics driven evaluation of its binding to DNA: Pseudo-binding of Curcumin to DNA	Physico-chemical studies in solution using copper acetate and Curcumin indicate the formation of a 1:2 CuII:Curcumin species. However, attempts to prepare it following the results of physico-chemical experiments always led to the formation of a 1:1 CuII:Curcumin species if CuII-acetate was used as starting material. In the absence of a single crystal or an appropriate powder X-ray diffraction data that allows solving the structure, it was arrived at by spectroscopy guided DFT calculations	[39]
Synthesis of Metal-Curcumin Complex Compounds (M=Na^+, Mg^{2+}, Cu^{2+})	Curcumin complex compound, MLn has been synthesized from the reaction between curcumin and metal precursors (NaCl,$MgS0_4.7H_20$,$CuC1_2$, $2H_20$) in ethanol under reflux conditions. Synthesis takes place through the reaction between the metal ions Na^+, Mg^{2+}, or Cu^{2+} as the central atom and curcumin as the ligand	[40]
Stabilization of Curcumin by Complexation with Divalent Cations in Glycerol/Water System	The purpose of the present study was to stabilize curcumin food pigment by its complexation with divalent ions like (Zn^{2+}, Cu^{2+}, Mg^{2+}, Se^{2+}), in "green media" and evaluate its stability in vitro compared to curcumin alone. The curcumin complexes were prepared by mechanical mixture of curcumin and sulfate salts of each metal (metal:curcumin 1/1mol) into unconventional and nontoxic glycerol/water solvent. Two stoichiometries of the complex were obtained, 1:1 and :2 (metal/curcumin), respectively	[41]
Curcumin interaction with copper and iron suggests one possible mechanism of action in Alzheimer's disease animal model	Using spectrophotometry, we quantified curcumin affinity for copper, zinc, and iron ions. Zn^{2+} showed little binding, but each Cu^{2+} or Fe^{2+} ion appeared to bind at least two curcumin molecules. The interaction of curcumin with copper reached half-maximum at ~3–12 µM copper and exhibited positive cooperativity, with $Kd1$~10–60 µM and $Kd2$~1.3 µM (for binding of the first and second curcumin molecules, respectively)	[42]
Curcumin binds to the pre-fibrillar aggregates of Cu/Zn superoxide dismutase (SOD1) and alters its amyloidogenic pathway resulting in reduced cytotoxicity	Using ThT binding assay, AFM, TEM images and FTIR, we demonstrate that curcumin inhibits the DTT-induced fibrillation of SOD1 and favors the formation of smaller and disordered aggregates of SOD1. The enhancement in curcumin fluorescence on the addition of oligomers and pre-fibrillar aggregates of SOD1 suggests binding of these species to curcumin. Docking studies indicate that the putative binding site of curcumin may be the amyloidogenic regions of SOD1	[43]
A novel curcumin assay with the metal ion Cu (II) as a simple probe by resonance light scattering technique	This assay applied the RLS technique with a common metal ion Cu (II) as the spectral probe. In the pH range of 6.5–7.5, the interaction between Cu (II) and curcumin occurred and the weak RLS intensity of Cu (II) was greatly enhanced by curcumin. The maximum peak was located at 538.5 nm. Under the optimum conditions, the enhanced RLS intensity was proportional to the concentration of curcumin ranging from 0.4 to 60_gml^{-1} with the detection limit of 0.07_gml^{-1}. The synthetic and human urine samples were determined satisfactorily	[44]
Curcumin attenuates copper-induced oxidative stress and neurotoxicity in Drosophila melanogaster	Curcumin possesses antioxidative, anti-inflammatory and anti-depressant-like properties. In this study, we evaluated the rescue role of Curcumin in $Copper^{2+}$-induced toxicity in D. melanogaster. Adult, wild type flies were exposed to Cu^{2+} (1 mM) and/or Curcumin (0.2 and 0.5 mg/kg diet) in the diet for 7 days. The results indicated that Cu^{2+}-fed flies had reduced survival compared to the control group. Copper toxicity was also associated with a marked decrease in total thiol (T-SH), as well as catalase and glutathione S-transferase activities, contemporaneous with increased acetylcholinesterase (AChE) activity, nitric oxide (nitrate and nitrite) and dopamine levels	[45]
Electrochemical Synthesis of Nanostructured Copper-Curcumin Complex and its Electrocatalytic Application towards Reduction of 4-Nitrophenol	The as-prepared complex was systematically characterized by various techniques. The scanning electron microscopy (SEM) images revealed that polycurcumin was formed in a rod-like structure while the Cu-curcumin complex was made up of spherical nanoclusters with an average size of 80 nm. UV-visible spectrophotometry and cyclic voltammetry data confirmed the formation of the Cu-curcumin (1:1) complex. Electrochemical impedance spectroscopy (EIS) data suggest that the charge transfer is very facile at the Cu-curcumin/GCE	[46]
Curcumin derivatives as metal-chelating agents with potential multifunctional activity for pharmaceutical applications	In this work, we examined the metal complexing ability of substituted curcuminoids to propose new chelating molecules with biological properties comparable with curcumin but with improved stability as new potential AD therapeutic agents. The K2T derivatives originate from the insertion of a $-CH_2COOC(CH_3)_3$ group on the central atom of the diketonic moiety of curcumin. They retain the diketo-ketoenol tautomerism, which is solvent dependent. In an aqueous solution, the prevalent form is the diketo one but the addition of metal ion (Ga^{3+}, Cu^{2+}) causes the dissociation of the enolic proton creating chelate complexes and shifting the tautomeric equilibrium towards the keto–enol form	[47]
Photocytotoxicity of copper(II) complexes of curcumin and N-ferrocenylmethyl-L-amino acids	Copper(II) complexes [Cu(Fc-aa)(cur)] (1-3) of curcumin (Hcur) and N-ferrocenylmethyl-L-amino acids (Fc-aa), viz., ferrocenylmethyl-L-tyrosine (Fc-TyrH), ferrocenylmethyl-L-tryptophan (Fc-TrpH) and ferrocenylmethyl- L-methionine (Fc-MetH) were prepared and characterized. The DNA photocleavage activity, photocytotoxicity and cellular localization in HeLa and MCF-7 cancer cells of these complexes were studied. Acetylacetonate (acac) complexes [Cu(Fc-aa)(acac)] (4–6) were prepared and used as controls	[48]

The results of measurements and calculations, as well as test results, indicate that there is an effect of spin on the aromatic ring on the concentration of curcumin on the copper coil. An increase in electric current along the copper coil results in an increase in the magnetic field strength and also the conductivity of the coil. The aromatic spin on the C–C bond on copper:curcumin powder provides electron donation of copper metal so that the electric current increases.

The external magnetic field interacts with the electrons of the curcumin molecule thereby inducing a current [24]. This magnetically induced current is used as a measure of aromaticity. By inducing a magnetic field in the description of quantum chemistry, the magnetically induced current density of a molecule can be calculated and processed to obtain a quantitative measure of aromaticity [27, 28].

The external magnetic field interacts with the electrons of the molecule by inducing a current. This magnetically induced current is useful as a measure of aromaticity. By inducing a magnetic field in the description of quantum chemistry, the magnetically induced current density of a molecule can be calculated and processed to produce a quantitative measure of aromaticity [20, 29].

From several points in the explanation of the experimental results, it follows that there is an increase in magnetic field strength, an increase in electric current, a decrease in the resistance value, an increase in the conductivity value, proving the research hypothesis. The concentration of curcumin:H_2O greatly affects the increase in electric current according to equation (4). Increasing the current also reduces the resistance and increases the conductivity of the conductor.

7. Conclusions

1. The magnetic field strength under the initial conditions was 2.54 μT, after being immersed in a concentration of 80 %:20 % curcumin:H_2O for 4.5 hours, the value of the magnetic field strength increased by 6.75 (166 %). This shows that the magnetic field strength will increase in direct proportion to the greater concentration of curcumin coated on the copper coil.

2. The electric current under the initial conditions was 0.72 mA, after experiencing the immersion process at the highest concentration of curcumin:H_2O, the current value increased to 1.1 mA (53 %). Increasing the concentration of curcumin as a copper coating will increase the current through the system.

3. The resistance values of the coils that have been coated with curcumin:H_2O concentration. From the level of percentage that is getting bigger, the resistance value of the conductor becomes smaller.

4. The conductivity level of the initial conductor of 28.80 $\text{ohm}^{-1}\cdot\text{cm}^{-1}$ increased to 44.00 $\text{ohm}^{-1}\cdot\text{cm}^{-1}$ (53 %) in the curcumin coating process with the highest concentration for 4.5 hours. The increase in conductivity value is directly proportional to the increase in curcumin concentration. This means that the resistance will get smaller.

5. The nature of the curcumin and copper bonds with Avogadro software, it can be shown from the table that the C-C bond relationship, an aromatic spin occurs with a wavelength of 1.52387–1.8972 Angstrom (1.52387×10^{-8}–1.8972×10^{-8} cm).

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The study was performed without financial support.

Data availability

The manuscript has no associated data.

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