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Design and Construction of an Electronic Water Softener

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Abstract: *Hard water has taste and wastes soap. An electronic water softener was constructed using the NE 555 electronic timer in a stable multivibrator mode. It was designed to operate at a frequency of 15 kHz and powered by a 12volt battery which delivered 150mA to the oscillator circuit. An activity indicator was designed to monitor the working state of the water softener. The water softener was tested on hard water samples obtained around Kaduna city. The results obtained indicated a total removal of hardness in mildly hard samples, and a great reduction of hardness level in very hard water samples used. The electronic water softener is an efficient and very cheap way of softening hard water that can be used in homes and industries.*

Key words: *Design, Construction, Water softener, Multivibrators and Oscillators.*

I. Introduction

Water is an odourless, tasteless and colourless or transparent liquid. It has a bluish tint, which may be detected in layers of considerable depth only. Under standard atmospheric pressure (760mmHg) the freezing point of water is 0^oC and its boiling point is 100^oC. Water attains its maximum density at a temperature of 4^oC and thence expands upon freezing (Nelkon, 1994).

Water is one of the best known ionizing agents, because most substances are soluble in water. It is the only substance that occurs at ordinary temperature in all the three states of matter: - solid, liquid and gas. It covers three quarters of the surface of the earth in the form of swamps, lakes, rivers and oceans. Under the influence of gravity, water accumulates in rock interstices beneath the surface of the earth as a vast underground reservoir supplying wells, springs and sustaining the flow of streams and rivers.

II. Literature Review

Since water has the capacity to dissolve numerous substances in large amounts, pure water rarely occurs in nature. In its movement over and through the earth's crust, water interacts with and dissolves minerals in the soil and rocks that it encounters. Principally groundwater dissolves; sulphates, chlorides and bicarbonates of sodium and potassium and the oxides of calcium and magnesium. (Ababio, 1992).Hard water is said to be water with a relatively high concentration of mineral salts, of these, the calcium compounds are particularly troublesome, since they reduce the effect of soaps and block filters, taps, shower-heads and other outlets of the domestic water supply system. The calcium compounds in copper tubes form a greenish substance that obstructs the flow of water where water is heated. As in coffee making and washing machines (Magsol, 2003). Hardness of natural water is caused largely by calcium and magnesium salts and to a small extent by iron, aluminum and other metals dissolved in it. Hardness resulting from bicarbonates of calcium and magnesium is called temporary hardness. The residual hardness is known as non-carbonate or permanent hardness (Goh Che Leong, 1977).

Test for harness in water can be carried out easily using soap solution. The soap solution is titrated against a known volume of distilled water. This serves as a standard to know the amount of soap solution required to form permanent leather in pure water. The same volume of hard water as that of the standard is then used to titrate against a fresh sample of the same soap solution. The excess volume of soap solution used indicates the degree of hardness in the water sample as compared with the standard from the distilled water (Ababio, 1992). Several methods are used for softening water. These range from ordinary boiling for removing temporary hardness, to the use of ion exchanges for permanent hardness. One method of softening permanent hardness includes the addition of sodium carbonate (also known as washing soda, Na_2C0_3), and lime in controlled amounts to the water. These cost money. The process of filtration through zeolite (an ion-exchange resin) which absorbs hardness-producing metallic ions, and releases sodium ions to the water is sometimes used. The problem of hardness of water in domestic works like washing and in laundry is so serious that a cheap and more convenient method of softening hard water is inevitable.

A water softener that is so inexpensive but very efficient was designed and constructed based on the theory developed as early as 1930. It states that an electromagnetic or electric field causes small calcium carbonate crystals in water to join and form larger crystals (Elektuur, 1991). This reduces the risk of calcium deposits on the inside of tubes, kettles and other water bearing vessels. The calcium concentration remains the same but deposits are reduced, since the crystals prefer to join others rather than attach to the walls of the vessel. The water is then softened and merely carries the crystals along. The field strength required is from 2.5 gausses which can be provided by a permanent magnet of a loud speaker. The magnet is placed next to or under the water supply tube. This is not very efficient.

The Electronic water softener operates at a frequency of 15 kHz and amplitude of 12 volts. A 555 timer IC was used to produce a rectangular-wave signal which induced the field required in the water supply passing through a tube using two open ended copper coils wound round it. The coils were insulated to prevent electrical contact with the tubes (Elektuur, 1991). An activity indicator was designed to detect the presence of the 15 kHz oscillator signal. This method has a greater advantage over the chemical methods owing to its cheap cost of construction, simplicity of operation and efficiency. It also neither adds chemicals to the water nor requires routine maintenance.

III. Oscillators

An oscillator in effect, converts power delivered by a direct current (d.c) supply into alternating current (a.c). Electronic circuits can generate a.c signals of a variety of waveforms over a wide range of frequencies. Transistor and vacuum tube oscillators are some of the convenient ways of generating high frequency voltages. They are widely used in radio, television transmitters and receivers and in electronic instruments for timing and testing purposes (John, 1978).

Oscillation is achieved through positive feedback which produces an output signal without any input signal. If the circuit conditions are arranged so that the multiplication/feedback factor β and the amplification factor α, are such that $\alpha\beta = 1$ then, for sinusoidal oscillations the feedback network is said to have attained the Barkhausen criterion. This is satisfied at only one frequency called resonant frequency f_o, and the circuit oscillates at that frequency. The Barkhausen criterion requires that the overall phase shift of the feedback signal be 360^o and this is a significant factor in determining the frequency of oscillation. In addition, the amplifier gain must be large enough to assure that $\alpha\beta = 1$ in order for the oscillations to persist. Oscillators are of various types based on their applications. There are Resistor-Capacitor (RC) oscillators, negative resistance oscillators and relaxation oscillators. Some of these oscillators are discussed below.

Resonant Inductor-Capacitor (LC) circuits are often used in the feedback network of oscillators to select the frequency of oscillation. Among the LC oscillators is the Hartley oscillator with a resonant frequency f_o, of the tank circuit in Hertz is given by $f_o = 1/\ \{2\pi(L_1+L_2)\ C\}$ (1)

In the Colpitt's oscillator, the inductors L_1 and L_2 are replaced by capacitors C_1 and C_2 while capacitor in Hartley is replaced by inductor.

The capacitors discharge across the inductor to the generate oscillations to generate a resonance frequency $f_o = 1/(2\pi\ (C_1C_2)/\{(C_1 + C_2)L\})^{1/2}$ (2) (Calvert, 1978). A phase shaft oscillator employs a conventional amplifier stage and an RC feedback network. The grounded emitter stage has an inherent phase shift of 180^o, and the three cascaded RC circuit shift the phase an additional 180^o in order to satisfy the Barkhausen criterion. At some particular frequency, the phase shift in each RC section network is 180^o and the circuit oscillates at this frequency, provided amplification is great enough. The frequency of oscillation is given by

$f_o = 1/(2\pi\ RC)$. (3)

Where $R_1 = R_2 = R_3 = R$ and $C_1 = C_2 = C_3 = C$

The phase shift oscillator oscillates at f_o given above in equation (3).

(Brain, 1993)

Multivibrators

Multivibrators are generally circuits which produce an output waveform continuously. The final output of multivbrators is usually a square wave. Multivibrations are generally grouped into: (i) Monostable, (ii) Bistable and (iii) Astable (Raymond, 1984).

Design and construction of the water softener

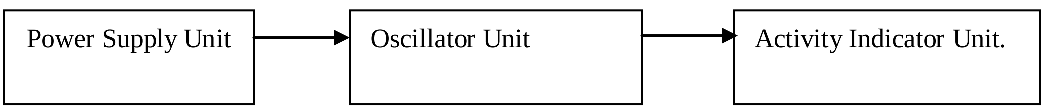

Fig.1 Block diagram of the water softener.

Design of the water softener

The 555 timer IC has maximum supply voltage of 15 volts and maximum supply current of 200mA (Iguana, 2003). That is;

Maximum input and output voltages = 15 volts

Maximum input and output currents = 200 mA

The frequency of oscillators of NE555 IC was determined sing the RC network in Figure (2) below.

Let t_c = charging time = $0.693 (R_1 + R_2) C$ (3)

t_d = Discharging time = $0.693 R_2 C$ (4)

Period (T) = $t_c + t_d$ (5)

Frequency (f) = I/T (6)

For frequency (f) = 15×10^3 Hz

Period (T) = $1/f = 1/15 \times 10^3 = 66.666 \times 10^{-6}$ s

Using;

R_1 = 10k

$R_2 = 10R_1$ = 100k for about 1:10 mark to space ratio.

Using equation (4), for $T = 66.67 \times 10^{-6}$ s

$C = 4.58 \times 10^{-10}$ F

$= 0.458 \times 10^{-9}$ F

= 0.45 nF.

Two capacitors $C_1 = C_2$ = 100nF were used. One at the input to control the unwanted radio frequency signals and the other at pin 5 to block the R.F signals. This capacitor offers a reactance of 106 ohm approximately to block the R-F signals.

Design of the activity indicator

The field effect transistor Tr. in the circuit is (BS170 FET) with the following transistor parameters:

Maximum input voltage = 60 volts.

Maximum input current = 0.3A

Maximum power rating = 0.83 watt

Frequency range = 10 kHz – 1000MHz.

De-rating at half maximum current, I_{DS} = 150mA. At 12 Volt supply the drain biasing resistor R_6 is given by,

R = V /1

$= 12/15 \times 10^{-3}$

= 2400Ω.

The source was grounded. When the gate was biased ON, the light emitting diode, LED connected to the drain would light to give an indication of the presence of the field needed.

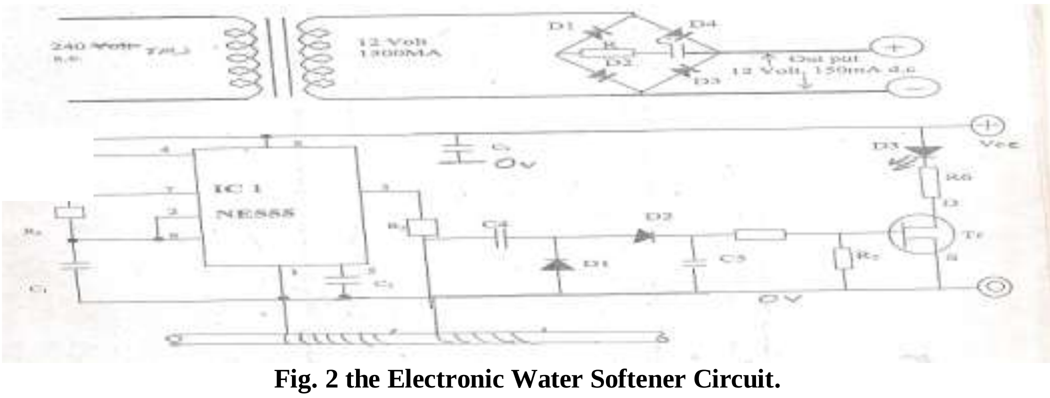

Fig. 2 the Electronic Water Softener Circuit.

Materials and methods used

Materials used for this work include;

1. Diameter of inductor wire = 0.8 mm
2. Outer diameter of the water pipe = 2.57 cm
3. Inner diameter f the water pipe = 2.41 cm
4. Number of turns of inductor wire at positive output = 77
5. Number of turns of inductor wire at the ground = 75
6. The gauge of the wire used for inductor = SWG32
7. Standard soap solution used = Morning fresh from P.Z Nigeria Limited

Construction
The circuit was constructed as shown in Fig.2 above.
The output from Pin 3 of the timer IC used was fed to a speaker which vibrated with the frequency.
Data collection
The hard water samples used were:
Samples A & B from Kaduna State Pilgrimage Cap, Mando, Kaduna
B & C from No. 23 Zango Road Tudun Wada Kaduna and
D & E from R12, Musa Umar Street, Mando, Kaduna
Data analysis
Flow rate used in litres/minute = 0.92 = 0.0153 l/s
Volume of distilled water used per titration = 25ml
Volume of soap solution used as standard V_0 = 2.0ml.
Soap solution was titrated against each water sample both before and after softening. The volume was recorded to the nearest 0.5ml
V_H = Volume of soap solution used for hard water sample.
V_S = volume of soap solution used for softened water sample.
$V_W = V_H - V_0$ is volume of soap solution wasted by hard water sample
Efficiency (E_{ff})
$E_{ff} = 100V_0 / V_S$ is percentage volume of soap solution saved by softening.
The values are shown in table 1 below.
Volume of soap solution used as standard V_0 = 2.0ml
Table1. Efficiency of electronic water softener.

SAMPLE	V_H (ml)	V_S (ml)	V_W (ml)	E_{ff} (%)
A	5.5	2.0	3.5	100
B	5.0	2.0	3.0	100
C	7.5	3.0	5.5	67
D	7.5	3.0	5.5	67
E	8.0	3.5	6.0	57
F	7.5	3.0	5.5	67

Conclusion

The softening shows over 50% in all cases and 100% in mildly hard water samples.
This means it could be concluded that this water softener works and can be applied in softening hard water. The following recommendations are therefore applicable: The appropriate flow rate at which the hard water can be best softened and the effect of the strength of the field used versus efficiency of softening should be investigated. Individuals and companies especially water board should see how this method of softening can be applied by them. Furthermore the electronic water softener can be employed in softening borehole water for use both domestic and commercial sachet (pure) water producers.

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