Design and Fabrication of a Local Colorimeter for the Developing Countries

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A colorimeter is a device which magnifies the quality of color perception to the human eye. It uses the light sensitive gadgets to determine the concentration of a solution in industries, hospitals and laboratories. This device can be used to measure, monitor or maintain the accuracy or purity of solutions like water and body fluid samples. Based on the Beer-Lambert law, it measures the absorbance of particular spectrum of white light or wavelength in a specific solution to determine the concentration of solutes dissolved in it. From the aperture the light beam is transmitted to the transparent curvettes that holds the test or control solution. Certain components of the light beam are absorbed while some are transmitted depending on the concentration of the solution. The portion of the light transmitted from the curvette falls on the photocell containing photoelectrical resistive material that converts the photo energy to electrical signal. The small signal (within the range of milliampere and picoampere) is amplified with transistors and measured by an analogue meter as transmittance. This device is locally designed with safety considerations. Further work can connect this colorimeter to a digital display meter or sent to a chart recorder, data logger or computer depending on the need of the operator.

Key words: Colorimeter, Design, color, concentration

1. Introduction

A colorimeter is a device used in the practice of colorimetry or the science of color. In scientific field it generally refers to a device used in the measurement of the absorbance of particular spectrum of white light or wavelength of light by a specific solution. The device was invented in the 16th century by Jan Szczpanik. The absorbance of a particular wavelength in colorimeter by a solution is used in the determination of its concentration of solutes dissolved in it. This is based on the Beer-Lambert law which concisely states that the concentration of a solute in a solution is proportional to its absorbance. Usually, a colorimeter takes three wide band reading along the visible spectrum to obtain a rough estimate of a colour sample. This is known when taken average of a TRISTIMULUS VALUE. In the basic colorimetric analysis, the test sample is visually compared to a known colour standard [1].

Colorimeter have found a wide range of uses most especially where purity of a solution with contaminants are of high importance like in hospitals, laboratories, and even industries. These include

Water purity tests.
Medical and clinical tests
Quality control tests
Research tests and analyses [2].

Major theories and principles applied in the design and operation of a colorimeter include:

Isaac-Newton's Theory of Dispersion of White Light [3].
The Beer-Lambert law [4].
Theory of Colour Combination .

2. Design and Fabrication

2.1 Major components in Design of a colorimeter

- A light source, usually an ordinary low-voltage filament lamp which can produce white light. In most cases when it is necessary to operate at ultraviolet range (below 400nm), filament lamps are replaced with several Light-Emitting Diodes (LED) of different colors.

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- An adjustable aperture which is manipulated by the operator of the colorimeter device to change the amount of light beam that passes through it to the filter.
- A set of colored filter: these changeable optic filters are used in colorimeter to select the wavelength of light which the solution absorbs the most, in order to maximize accuracy. The wavelength range of colorimeter is from 400nm-700nm which is the range of visible light. In exceptional cases ultraviolet range (below 400nm) can be used.
- Curvettes: this is used in holding the working solution. It comes in different sizes and ranges. They are made of transparent plastic or glass. For modern digital photoelectric colorimeter, curvettes may come in ranges like round 10mm internal diameter, 12mm outside diameter, 105 mm square.
- Photodetector which is usually a photo resistor is used to measure the light transmitted from the curvettes. It is made up of photocells which are able to detect the amount of light which passes through the solution under investigation. The more light that hits the photocells, the higher the current it produces hence showing the absorbance of light.
- A Meter: which can either be an analogue or digital meter that displays result based on transmittance, absorbance, and concentration from the detector? The photometric range of the output is usually 0-100% for transmittance and 0-1.999Abs for absorbance and 0-1999 for the concentration.
- Other minor components are:

- Voltage regulator to protect the instrument from fluctuation of mains voltage.

- A second light path, curvette and detector: this enables comparison between the working solution and a standard solution with a known concentration or a colorless sample (blank).

- A blank consists of pure solvent. This method of comparison helps to improve accuracy.

- In addition, for record purposes user may decide to send output to a chart recorder, data logger or computer for storage.[5]

2.2 Locally Sourced Materials for the Colorimeter

- Light Source: A 12V bulb is used which produces a white light in the in the designing of the light source. The bulb contains a filament and its attached to a fitting lamp holder which is connected to the rest of electrical circuit.
- Adjustable Aperture, made from a coated iron alloy. It is made to have a hole through which light will pass. Then a blocker which is also made from same materials and is attached with a bearing ball which can be controlled by a knob that can be turned manually to the left or the right. The turning of the knob closes the hole completely, closes the hole partially or opens it completely.
- Set of Coloured light filter, actually made from a thin film of acrylic plastics which are of different colors ranging from red to violet in the light spectrum. They are made to be removable so that the needed film can be placed or removed when there is need.
- Curvette is a small container which is either cuboidal or cylindrical in shape but in our case we have a cuboidal curvette which is open at the top part so that the fluid can be poured into the container through the open part. It is made from transparent thermoset plastic. The glass is transparent because proper light transmission and absorption by the fluid need to be ensured. The thermoset plastic is a hard plastic that is not usually corrosive with any fluid poured into it and cannot easily melt due the small amount of heat coming from the light.
- Detector is a simply a photo sensitive material which reacts to the light sensing by varying its resistance (and voltage). This material is kept in such a way that any slight lighting can be sensed without actually doing any mechanical movement. A small telephone wire runs from the photodetector to the meter where the variation in wavelength is transmitted.
- Meter is actually made from a recalibrated galvanometer with the normal spring and pointer technology. A paper with the new graduation of galvanometer is attached to pointer which is calibrated in both absorbance and transmittance. The

telephone cable runs from the photodetector to the analogue meter which gives the output result of the photodetector electric signal.

2.3. Arrangement of Components and Fixtures

Some of the basic things considered during the arrangement of the components are its ergonomics, parts that needs to be accessible to the operator, aesthetics and safety. After due consideration of these points, we decided to use a small box-like metal casing coated with oil paint, with an opening at the top to facilitate easy use. The bulb was placed in the inside away from the reach of the ordinary user. This is to ensure that there is no case of disrupting the electrical circuit although a switch to control the bulb is attached at the top of the metal casing so that the operator can easily flicker on or off the bulb.

Also inside the metal casing away from the operator's access lies the adjustable aperture which is to be controlled by a knob at the top of the metal casing. The aperture is meant to be inside to avoid user from disrupting the arrangements that slides the blocker to close or open.

The light filter compartment is meant to be seen from the top and to be easily accessed by the user since light filter of different wavelength will be inserted and removed by the user as when desired.

Just very close to the filter compartment is the curvette compartment since the whole light beam transmitted from the light filter needs to enter the curvette without diffusing away. It is also made accessible from the top of the metal casing as the user may regularly remove the curvette either to add or remove the fluid or even wash the curvette after use.

Inside the metal casing away from the user but very close to the curvette is the photodetector which receives the light transmitted from the curvette. To avoid electrical hazard and maintain accuracy, it is still kept away from the user.

The display meter (an analogue galvanometer) is placed on top of the metal casing to be viewed very well by the user and to maximize ergonomic positioning. The connection between it and the photodetector is hidden from non-technical access. Thus ergonomic safety is assured.

Figure 1: The Locally fabricated Colorimeter

On top of the display meter is glass covering which is used to enhance the aesthetics and protect the display meter. Very close to the glass are the knob for adjusting the aperture; an indicator to show when the device is connected to a.c or not, and a switch for turning on the bulb and especially for starting off the process of using the device.

The most important objective achieved during the designing and fixing is simplicity of operation and accuracy of readings.

2.4 Mechanism of Operation of the Colorimeter

The mechanism of operation of the colorimeter starts from turning on the 2-way switch that regulates the power supply to the bulb producing the light source (white light). When the bulb comes on it produces a beam of white light that moves to the light filter. The light filter absorbs every other wavelength of the white light except the wavelength that it is supposed to transmit. Usually the choice of which light filter to use in order to get the required wavelength transmitted is done by the operator of the colorimeter based on the principle of color combination. Thus the main function of the light filter is to "filter" the white light and transmit the wavelength of choice for the test. Usually, the wavelength range selected is between 400-700 nanometer (nm) which is the visible light spectrum.

From the light filter the beam of the selected wavelength is transmitted to the adjustable aperture. The main function of the adjustable aperture is to focus the beam of light to one direction and ensure that scattered light beam is shielded away from being transmitted. The adjustable aperture also helps in increasing the intensity of the light beam for greater effect when it gets to the solution.

From the aperture the light beam is transmitted to the transparent curvette that holds the fluid for test or the control solution. Some components of the light beam are absorbed while some portions are transmitted depending on the concentration of the solution for test. The principle still holds that the more concentrated a solution is, the more light is absorbed and the less light is transmitted and vice versa (Beer-Lamberts' Law). The portion of the light transmitted from the curvette falls on the photocell.

The major function of the photocell made of photo-electrical resistive material is to convert the photo energy that falls on it from the curvettes to electrical signal which can be measured by the digital display meter. The amount of electrical signal produced is proportional to the amount of light transmitted by a solution.

Usually, the signal that comes from the photocell is so small (within the range of milliampere and picoampere) and thus amplifiers which are in form of transistors are connected between the photocell component and the display meter.

The output of the test is a numeric value which is displayed on an analogue meter. However the results can be displayed with digital meter and may be shown as transmittance (a linear scale from 0-100%) or as absorbance (a logarithmic scale from zero to infinity). Sometimes also output may be sent to a chart recorder, data logger or computer depending on the need of the operator.

3. Major Electrical Design in the Colorimeter

- Production of White Light: a three pin-plug is plugged to the mains connected through a 1.5mm cable to a 2-way switch serving as a control switch.
- A fuse (circuit breaker) is installed to protect the device from high-voltage current that may damage sensitive electrical components.
- A connected transformer (1000w) steps down 240v to 12v that is nearly required for the bulb that will serve as the light source. The secondary voltage of 12v is passed through a panel board (circuit board) made up of a bridge rectifier (that will serve the purpose of converting the alternating current to direct current), resistors (which will reduce the slightly high voltage to the exact 12v required by the light bulb) and some electric component connectors. The current from the panel is now connected by a special cable known as telephone cable to the 12v light bulb.
- Connection of the photodetector (energy converter) to the display analogue meter. The detector is equipped with a transistor (amplifier) which amplifies the micro ampere signal coming from the detector. From the amplifier, it is connected to the calibrated galvanometer (display meter) that yields the result of the signal using the pointer.

The circuit completes the electrical designs implemented in the colorimeter [6].

3.1 Electrical Safety Considerations:

- Safety of the User: measures are taken to avoid electrocution accident while using the device.
- Safety of the device: measures are taken to prevent damage during operation of the electrical component.
- Safety of the other components of the device to ensure accuracy.
- Oil painted metal casing is used to ensure protection against electrical surge and proper installation.
- Electrical components are kept separate in another compartment away from other components.
- The 2-amperes maximum voltage fuse (circuit breaker) is used to break the circuit in order to

protect the life of the device.
- The use of a 2-way switch to control the circuit.
- The equipment will not affect the physical environment adversely as the transparent plastic covering to prevent exit of infectious samples.
- Other safety features include: easy to operate with accessible parts; portable with light, strong and low density material; easy to use while sitting or standing; oil painted smooth and non corrosive surface and minimized heat production by use of 12v instead of 6v bulb. (Gaurav, 2002 and Salvaggio, 2007)

4. Recommendations and Conclusion

Some of the areas for further research in colorimetry include:
- An automated light intensity variation design.
- A multi testing design
- A digital display design
- In built, automated light filter/wavelength varying design.

As human needs for assessment of solutions increase by the day and as we strive to achieve efficiency and safety with the local biomedical equipment, greater demands are placed on the design and fabrication of a local colorimeter for the developing nations like Nigeria.

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