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Optimization of Sealing Temperature in Tarpaulin Welding Machines for Performance Enhancement

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ABSTRACT
Automating tarpaulin cutting and sealing is crucial for efficient mass production. This study aims to determine optimal sealing temperatures for various tarpaulin materials. A model was developed using heat transfer principles and mathematical tools. The fabricated machine achieved precise sealing temperatures: HDPE at 1550°C, PVC at 1200°C, and LDPE at 1100°C. It demonstrated 90.4% energy savings compared to existing machines while maintaining seal strength. Local production of such machines could reduce costs associated with imported equipment.
Keywords; *Tarpaulin, sealing machine, heat transfer, temperature control.*

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I. INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Automatic Tarpaulin Sealing and Cutting Machine: A Critical Industrial Device

This machine simultaneously seals and cuts tarpaulin into various sizes, crucial for plastic products and industrial processes requiring temperature control. Tarpaulin, a synthetic rubber sheet for waterproofing, can be formed into diverse shapes.

The device is essential for:

- Agricultural sector
- Food processing industry
- Transportation of goods

Temperature control is vital in plastic manufacturing, affecting injection-molded product quality. Proper heating and cooling rates are crucial for optimal mold quality.

In various industrial systems, temperature controls maintain safe, efficient operation and prevent component damage. Operating outside the optimal temperature range can lead to system failure, resulting in downtime, increased labor, and higher costs.

II. LITERATURE REVIEW

Auvil and Davis developed a technique for coal-heating preheating equipment using a heat-absorbing liquid. The ideal temperature range is 250-700 °F.

Ji et al. published on an Electromagnetic Heating Temperature Control System using LADRC.

Jiang et al. designed an electric heating temperature controller based on a nonlinear model.

Kaluvan and Kumar developed an air heating temperature controller using the SR approach.

Parts et al. examined optimal PI control settings for underfloor heating, addressing over-dimensioning issues in low-energy buildings.

III. METHODOLOGY

3.1 TEMPERATURE MODEL FOR TARPAULIN SEALING MACHINE

Using First Order plus Dead Time to Model Temperature (FOPDT). In this paper, the transfer function of the system model was determined using a first-order system. The study's mathematical model is represented by

$$\frac{T(s)}{U(s)} = \frac{K}{\tau s+1} e^{-tds} \qquad (3.1)$$

Rise time (τr), settling time (ts), delay time, ts time delay, K is a gain value, and τ is the time constant (td). The gain K can be found using the following method:

$$K = \frac{Tss - T0}{\Delta u} \quad (3.2)$$

Meanwhile, to find τ, it is necessary to know the temperature value at $T\tau$ which is obtained using.

$$Tr = \frac{63.2}{100}(Tss - To) + To \quad (3.3)$$

As a result, using a curve model to find the temperature point yields a temperature $T\tau$. Time at the present point $T\tau$ can then be calculated. The τ value is the predefined time based on the temperature $T\tau$.

According to the equations, the tarpaulin sealing machine's control object is a standard first-order delay system from a control perspective. One way to express the transfer function is as follows:

$$G(S) = \frac{K e^{-\Omega S}}{TS+1} \quad (3.4)$$

K represents the controlled object's static gain, Ω represents its pure lag time, and T represents its time-constant.

The latent heat of fusion of the tarpaulin material is involved in this process since heat is lost from the electric heater to the tarpaulin material.

$$Q = ML + MC(\Delta\Theta) = M(L + C(\Delta\Theta)) \quad (3.5)$$

Knowing that

$$Q = IVT = I^2RT \quad (3.6)$$

Where Q is the heat energy

I is the current consumed during the process

V is the supply voltage

T is the time duration during sealing

R is the resistance of the heating element

M is the mass of the material under sealing

C is the specific heat capacity

L is the latent heat of fusion

ΔΘ is the change in temperature during the sealing process.

And the value of L is 146 kj /kg,

While the value of C is 1670 J/Kg ^{O}C.

3.1.1 MODELING OF THE HEAT TRANSFER ON EQUATION (3.5)

$Q = ML + MC(\Delta\Theta) = M(L + C(\Delta\Theta)$ with

$Q = IVT$

THUS

$IVT = M(L + C(\Delta\Theta))$

Making I the subject formula

Thus

$$I = \frac{M(L+C(\Delta\Theta)}{Vt} \quad (3.7)$$

From equation (3.7), a model of the system was developed using Matlab, from where the various data will be generated and analyzed.

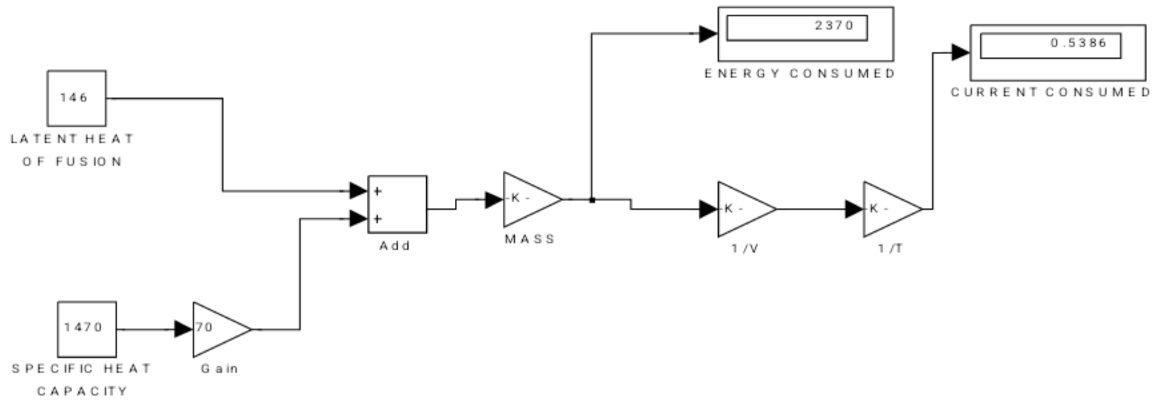

Figure 3.1 Matlab model of the temperature.

3.2. CALCULATING THE WELD STRENGTH OF THE TARPAULIN MATERIALS,

$$\sigma = \frac{Force}{Area} \qquad A = \frac{\pi d^2}{4} \tag{3.8}$$

Where σ = Stress, F= Force applied on the tarp material, A= Area of the tarp material space.

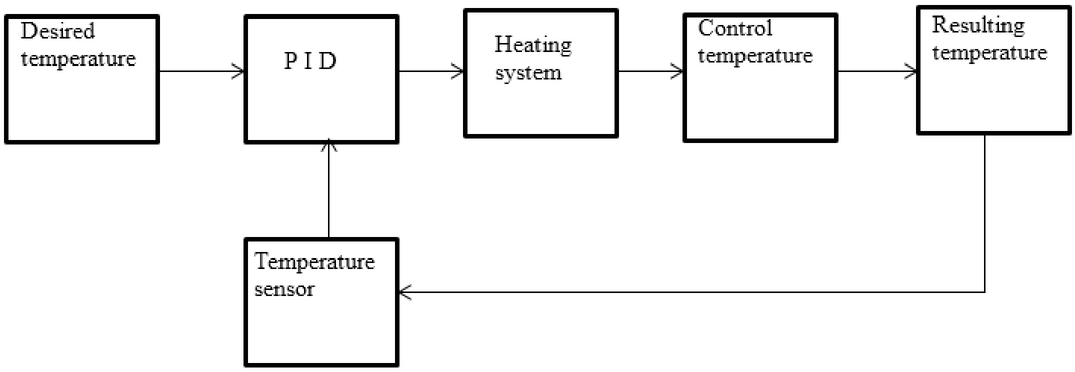

Fig 3.8 System block diagram

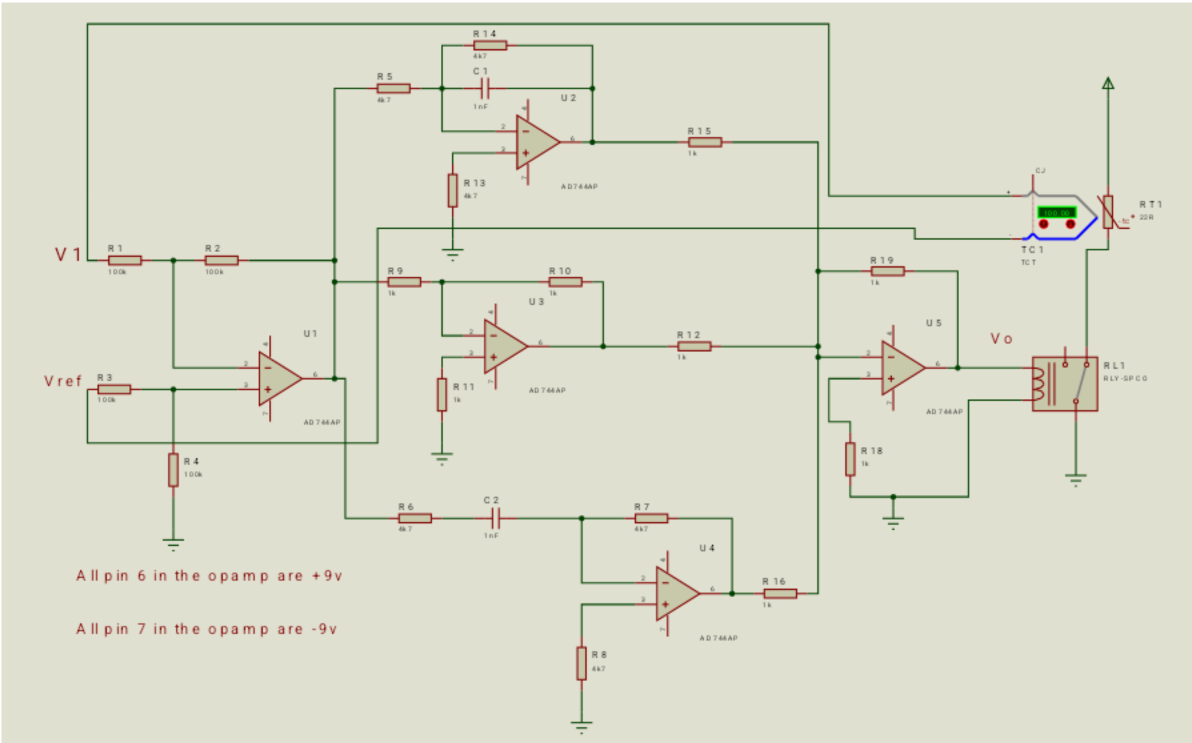

Fig 3.10. Circuit diagram of the control system.

3.2.1. OPERATION OF THE CONTROL SYSTEM

The thermocouple adjusts temperature based on the desired setting, feeding data to the central unit for comparison. The relay unit determines if the saturation temperature is reached, triggering ON/OFF. The system compares reference voltage with thermocouple voltage. The PID controller processes the error signal, controlling the heater relay. When maximum temperature is reached, the error signal drops, adjusting the relay operation

IV. RESULTS AND DISCUSSIONS

4.1. RESULTS

For each of the tarpaulin materials used for the experiment, the temperature was changed in relation to time in seconds (s) in order to record the test result. The temperature and duration ranges for the different tarpaulin materials are 1000°C to 1550°C and 1 to 6 seconds, respectively.

The following are three tarpaulin material samples that were examined using the locally built apparatus:

Table 4.1 tarpaulin type, uses and thickness.

Tarpaulin type	thickness	Material use
High-density polyethylene tarpaulin (HDPE)	0.78mm	They are a high quality tarp material that resists corrosion, abrasion and absorption. They are excellent materials for making truck covers, fish ponds, swimming pool covers, and camping tents.
Polyvinyl tarpaulin (PVC)	0.37mm	They are made from polyester fabrics and coated with pvc films. The pvc tarps are most suited for heavy duty covers, tents, canopies, and banners.
Low-density polyethylene tarpaulin. (LDPE)	0.29mm	They are of remarkable quality and are resistant to water, corrosion and abrasion. They are mainly used for making scaffoldings, billboards, banners, shop covers, truck covers etc.

Table 4.2. Table of result obtained from the fabricated sealing machine.

Tarpaulin material	Optimal seal temperature	Current (I)	Weld strength
High-density polyethylene (HDPE)	155^0C	3.2AMPS	6.22N/m^2
Polyvinylchloride (PVC)	120^0C	2.9AMPS	1.80N/m^2
Low density polyethylene tarpaulin (LDPE)	110^0C	2.74AMPS	0.81N/m^2

Table 4.3. Table of result obtained for current, and weld strength, for the conventional machine. **(HUASHENG HF WELDING MACHINE)**

Tarpaulin material	Optimal seal temperature	Current (I)	Weld strength
High-density polyethylene (HDPE)	Nil	8.5AMPS	6.16N/m^2
Polyvinylchloride (PVC)	Nil	7.5 AMPS	1.74N/m^2
Low density polyethylene tarpaulin (LDPE)	Nil	6AMPS	0.79N/m^2

The seal test was performed on the three selected samples, with Time 1, Time 2, Time 3, Time 4, Time 5, and Time 6 standing for one, two, three, four, five, and six seconds, respectively. Additionally, the tarp material was shown to be properly and perfectly sealed at the predetermined temperature using the sign (√), and it was shown to be poorly or imperfectly sealed at the same temperature and time using the symbol (X).

4.1.1 Test for the HDPE Tarpaulin material.

Table 4.5 summary of the fabricated machine sealing time for the HDPE type tarpaulin with respect to different temperature ranges.

s/n	Temperature in °c	Time in seconds(s)
1	100	12
2	105	11
3	110	10
4	115	9
5	120	8
6	125	7
7	130	6
8	135	5
9	140	4
10	145	3
11	150	2
12	155	1

Graphical representation of sealing time against temperature range for HDPE type of tarpaulin.

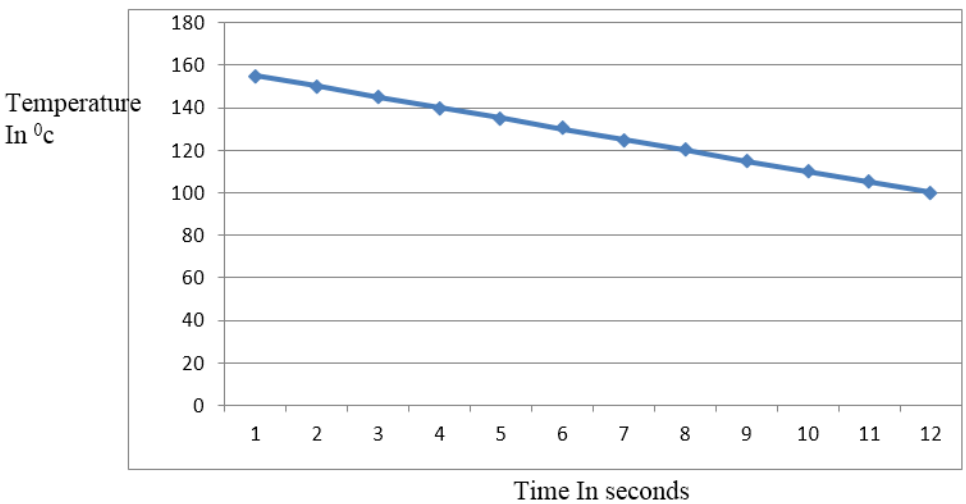

Figure 4.1 Graph of temperature against time for HDPE from the fabricated sealing machine.

According to the curve in Figure 4.1, the temperature at which the tarpaulin seals decreases

Time In seconds

as the period at which it does so increases. The graph's slope can be used to determine the temperature range at which effective sealing will occur in relation to time. Although most of the seal ranges were tried until the ideal temperature and duration were reached, a number of temperature ranges were applied from the points when sealing occurred. From the lowest temperature range to the highest, the sealing temperature was preset. Time of seal was also taken into account because the ideal seal was influenced by the actuator's pressure and the heating element's temperature.

4.1.2 Test for the LDPE Tarpaulin material.

Table 4.7 Summary of sealing time for LDPE type tarpaulin with respect to different temperature ranges when used with the fabricated machine

s/n	Temperature in °c	Time in seconds(s)
1	60	11
2	65	10
3	70	9
4	75	8
5	80	7
6	85	6
7	90	5
8	95	4
9	100	3
10	105	2
11	110	1

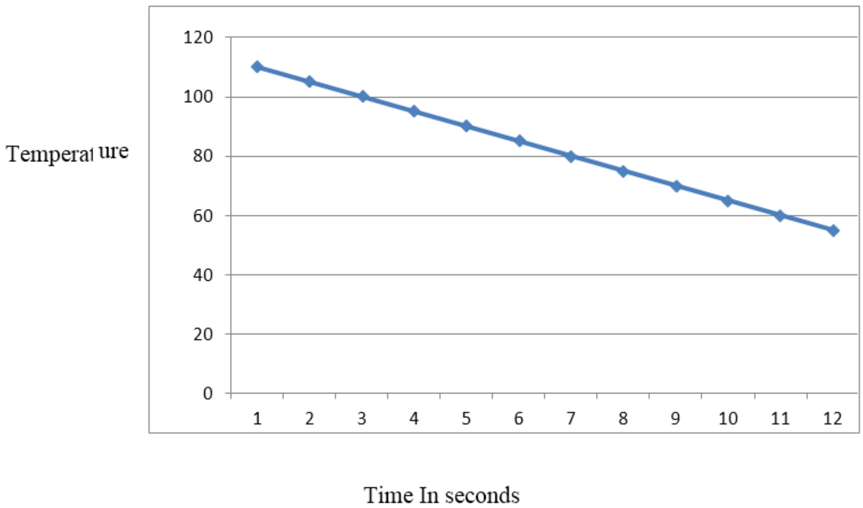

Figure 4.2 Graph of temperature against time with the fabricated machine for LDPE

Table 4.9 summary of sealing time for PVC type tarpaulin with respect to different temperature ranges when implemented with the fabricated machine.

s/n	Temperature in °c	Time in seconds(s)
1	70	11
2	75	10
3	80	9
4	85	8
5	90	7
6	95	6
7	100	5
8	105	4
9	110	3
10	115	2
11	120	1

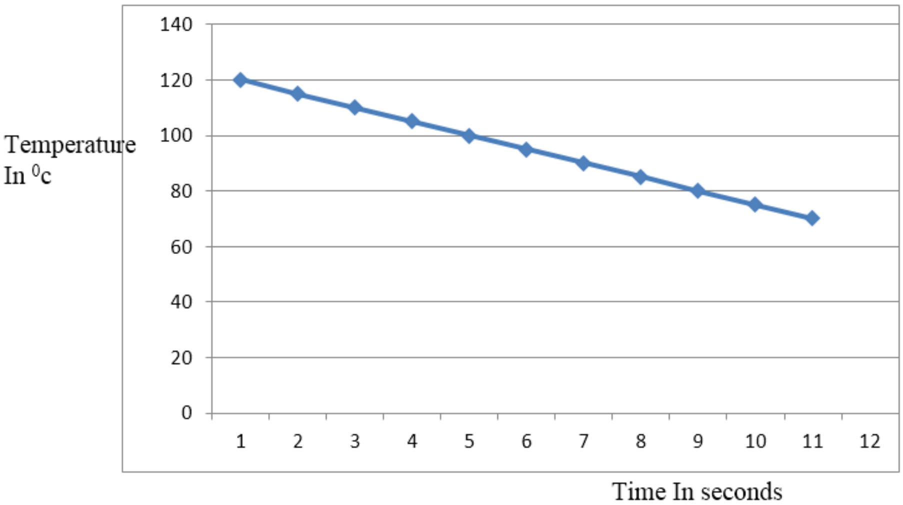

Figure 4.3 Graph of temperature against time for PVC tarpaulin type when used with the fabricated machine.

As can be seen from the accompanying graph, the temperature at which the tarpaulin seals decreases with increasing sealing duration. The graph's slope can be used to determine the temperature range at which effective sealing will occur in relation to time.

Table 4.9. Summary table of Matlab model for temperature change against energy and current consumed with the fabricated machine.

s/n	Temperature rise in °C	Temperature changes	Energy consumed In Joules	Current consumed In Amps
1	100	60	2032	0.46
2	110	70	2370	0.54
3	120	80	2708	0.62
4	130	90	3046	0.69
5	140	100	3384	0.77
6	150	110	3722	0.84
7	160	120	4061	0.92

4.2 RESULT DISCUSIONS

The selection of the three tarpaulin material types was based on their overall use to society and man. The most often utilised tarp materials in our settings, apart from the many others, were HDPE, PVC, and LDPE.The HDPE tarp type is a high-grade material with corrosion resistance that is appropriate for a variety of applications, including military tents, heavy vehicle coverings, and fish ponds.

4.2.1 Calculating the weld strength for the fabricated tarpaulin machine

Weld strength for HDPE tarp material

$$\frac{3.142X(0.024)^2}{4} = 45.445m^2$$

$$\sigma = \frac{283}{45.445} = 6.22N/m^2$$

Calculating the weld strength for the modeled PVC tarp material

$$\sigma = \frac{82}{45.445} = 1.80N/m^2$$

Calculating for weld strength for the modeled LDPE tarp material

$$\sigma = \frac{37.5}{45.445} = 0.81 N/m^2$$

4.2.2 Calculating the weld strength for the conventional tarp machine

Weld strength for HDPE tarp material

$$\sigma = \frac{280}{45.445} = 6.16 N/m^2$$

Calculating the weld strength for the conventional PVC tarp material

$$\sigma = \frac{79}{45.445} = 1.74 N/m^2$$

Calculating the weld strength for the conventional LDPE tarp material

$$\sigma = \frac{36}{45.445} = 0.79 N/m^2$$

4.3 Calculating for the energy consumed by the fabricated machine.

From equation (3.5).

$Q = ML + MC (\Delta \Theta) = M (L + C (\Delta \Theta))$

With $Q = I^2RT$

Equation 3.5 is used to analyze temperature variations' impact on energy consumption. The fabricated model demonstrates temperature-dependent energy usage, unlike the comparative system. The modeled machine consumes less energy than the HUASHENG HF WELDING MACHINE due to adjustable temperature settings for various tarpaulin materials.

A 750W (1 HP) compressor provides necessary pressure, contrasting with the 2.5 HP compressor in the refurbished machine. The modeled machine's heat element (2 feet, 15 ohms) directly contacts the material, requiring less power for sealing.

4.3.1 Calculating the current of the (HUASHENG HF WELDING MACHINE) machine being compared

using the equation

POWER = IV (4.1)

With the compressor of the **HUASHENG HF WELDING MACHINE** being 2.5HP which is (1875 watt) using 220 volts. The current is then calculated as

I = P/V = 1875 / 220 = 8.5 amps.

4.3.2 Calculating the energy emitted for 10 seconds by the heat element of the fabricated machine using

I^2Rt (4.2)

Thus.

$(8.5)^2 \times 25 \times 10 = 18062.5$ joules

So this is the amount of energy consumed by the tarpaulin sealing machine in the market

4.3.3 Calculating the current of the fabricated sealing machine

The horse power is 1 HP. (750 watts) using the same 220 volts.

Therefore the current is calculated as such,

I = W/V = 750/ 220 = 3.4amps

4.3.4 Calculating the energy consumed by the heater element for the fabricated machine

I^2RT (4.3)

Thus

$(3.4)^2 \times 15 \times 10 = 1734$ joules.

4.3.5 Calculating the percentage difference obtained from the fabricated machine and the HUASHENG HF WELDING MACHINE in the market.

The magnitude of the difference in energy consumption when the two machines were compared:

18062.5 -1734 = 16328.5

The energy difference will be,

16328.5/18062.5 x 100 = 90.4 %

With the percentage difference obtained it shows that the fabricated machine is efficient with less power use.

In view of the welding strength, as was demonstrated in Table 4.3, it can be seen that the fabricated sealing machine has a good welding strength and its strength is compared with the (HUASHENG HF WELDING MACHINE) in use. Also the value of the cost importation of the foreign machine is varied with the fabricated type can be produced at the cost of Nine hundred and fifty thousand naira (₦ 950,000) while the imported type costs over 2.5 million. This makes the locally modeled type more economical than the imported type.

V. CONCLUSION AND RECOMMENDATION

5.1 Summary Higher temperatures facilitate faster tarpaulin sealing due to increased electron mobility.
5.2 Contribution Locally fabricated machine with precise temperature control for specific tarpaulin types.
5.3 Recommendations Suitable for various tarpaulin materials; promotes local manufacturing.
5.4 Conclusion Demonstrates feasibility of local tarpaulin sealing machine production in Nigeria. The model offers temperature ranges for different materials, improving upon existing machines.

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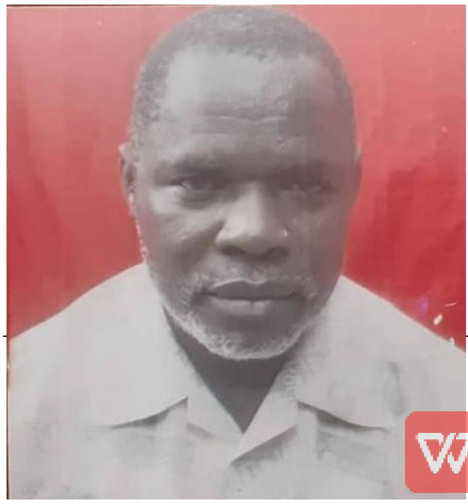

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