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Highlights

Investigation of Various Forms

Development of Analytical Model

Federal Housing Estate in Lagos

Ofpenicillin Fermentation Process

Discovering Thoughts, Inventing Future

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Development of Analytical Model for a Vertical Single U-Tube Ground-Coupled Heat Pump System

By Ali H. Tarrad
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Abstract- An analytical model was built to study the thermal design of a single vertical U-tube coupled heat pump under steady-state conditions. It was based on the philosophy of U-tube replacement by an equivalent thermal resistance situated between the heat transfer medium that flows inside the tube and the borehole boundary. An obstruction factor was introduced to account for the reduction of heat flow from or to a tube in the borehole due to the presence of the second leg of the U-tube. Two Copper U-tubes with wall factors of (12.5) and (14.29) were implemented to comprise several borehole configurations to verify the present work. The shank spacing was ranged between (2) and (4) times the U-tube outside diameter producing shank spacing to borehole diameter ratio range of (0.29-0.59). The model was utilized for the assessment of DX ground heat exchangers works as a condenser for cooling purposes. Reducing of the tube spacing to tube outside diameter ratio from (3.3) to (2) for both tube wall factors showed a rise for the borehole thermal resistance in the range of (22-54)% and (26.5-28)% predicted at wall factors of (12.5) and (14.29) respectively.

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Keywords: borehole thermal resistance, analytical modeling, thermal resistance correlation, DX heat exchangers, R-410A.

I. Introduction

The ground has been utilized since the forties of the last century as an energy source, an energy sink, or for energy storage. This was done in a parallel effort of developing efficient heat pumps to raise this heat source to a higher level of temperatures for heating purposes or heat rejection for cooling purposes. Augmentation of efficiency led to tremendous research to improve the performance of the ground part of the heat pump system. Hence qualitative and quantitative work was focused on the thermal design of the ground heat exchanger, vertical and horizontal orientations.

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Naili et al. [1] studied experimentally a horizontal ground source heat pump system in the cooling mode. The heat pump COP and the system COP were found to be (4.25) and (2.88), respectively. Bakirci [2] evaluated the performance of a ground-source heat pump system in a cold climate region. The experimental results indicated that the average heat-pump COP values are approximately (3) and (2.6) in the coldest months of a heating season. Fan et al. [3] conducted a theoretical study on the performance of an integrated ground-source heat pump system. The results refer to various factors affecting the performance of the vertical heat exchangers and hence the performance of the heat pumps system. Esen et al. [4] studied experimentally the transient temperature distribution inside a borehole for a vertical U-tube heat exchanger at (30, 60, and 90) m depth and (150) mm borehole diameter. A two-dimensional finite element model was built, and ANSYS code was implemented for the numerical analysis to predict the temperature distribution. They concluded that the numerical analysis appears to be most promising for predicting the response of GHEs to thermal loading.

Wood et al. [5] studied the heat pump performance and ground temperature of a ground heat exchanger system for a residential building. The seasonal coefficient of performance of the heat pump was found to be (3.62), and the temperature at (5) m was undisturbed. Florides et al. [6] investigated the thermal performance of a double U-tube GHE and the assessment of its efficiency with regard to its building cost. A numerical model was also developed for energy flows and temperature changes in and around a borehole. It was validated upon comparing its results with established experimental results for a single GHE.

Liao et al. [7] studied numerically the effective borehole thermal resistance of a vertical, single U-tube ground heat exchanger for a range of shank spacing. They claimed that their study produced a correlation that showed better accuracy than available correlations. Sharqawy et al. [8] postulated a 2-dimensional numerical model for the steady-state heat conduction within the borehole. He developed a correlation for the effective borehole thermal resistance and was also concluded that his correlation predicted the thermal resistance better than other available formulas. The

analytical models for (GHE) utilize mainly a line heat source [9, 10] and cylinder heat source theory [11, 12] to predict the heat transfer rate between the ground and the heat carrier fluid flowing in the (GHE).

The equivalent diameter of U-tube can be presented in the form of:

$$d_e = \beta d_o \quad (1)$$

Where (β) is an equivalency coefficient greater than (1.0). Claesson and Dunand [13] postulated the value of (β) for two buried horizontal pipes to be ($\sqrt{2}$).

Shonder and Beck [14] implemented a one-dimensional heat transfer model for the U-tube and arrived at the same value as that of Claesson and Dunand [13] for a single vertical U-tube heat exchanger in the form:

$$R_{f=} \frac{ln\left(\frac{D_B}{\sqrt{n}\, d_o}\right)}{2\,\pi\, k_g} \quad (2.a)$$

In which the equivalent diameter corresponds to:

$$d_e = \sqrt{n}\, d_o \quad (2.b)$$

Where (n) is equal to (2) for a single U-tube system and is corresponding to (2 do) for double U-tube ground heat exchanger. Gu and O'Neal [15] utilized a steady-state heat transfer simulation based on the cylindrical source model to produce a correlation for the grout resistance for a vertical U-tube ground heat exchanger in the form:

$$R_{f=} \frac{ln\left(\frac{D_B}{d_o}\sqrt{\frac{d_o}{S_p}}\right)}{2\,\pi\, k_g} \quad (3.a)$$

This form of equation reveals that the equivalent diameter was expressed as:

$$d_e = \sqrt{S_p\, d_o} \quad (3.b)$$

Koenig [16] has analyzed the heat transfer problem in a borehole with single and multi-vertical U-tube loops. He has arrived at an analytical solution to the borehole thermal resistance for different U-tube geometry configuration and presented a validation for the model with acceptable accuracy limits. Tarrad [17] reported a simple correlation for the prediction of a borehole thermal resistance in a vertical single U-tube ground heat exchanger incorporates the following expression of the equivalent diameter:

$$d_e = \frac{D_B}{\left(x+\sqrt{x^2-1}\right)} \quad (4.a)$$

$$x = \frac{{D_B}^2 + {d_o}^2 - {S_p}^2}{2\, D_B\, d_o} \quad (4.b)$$

The correlation showed an acceptable agreement with previously available ones in the open literature. More recently, Tarrad [18] developed a correlation to predict the borehole thermal resistance in which the equivalent tube was derived as:

$$d_e = \frac{\sqrt{2}\, d_o + 2\, d_o}{2} \approx \sqrt{3}\, d_o \quad (5)$$

The correlation showed excellent agreement with previously published expressions in the open literature.

In this study, the thermal resistance of the grout was coupled with the tube resistance to accomplish a model for the assessment of effective borehole resistance. The obstruction to heat conduction inside the borehole due to the presence of the second tube leg was also studied, and a correlation was addressed for this purpose. The shank spacing was ranged between (2) and (4) times the U-tube outside diameter producing a geometry factor (ζ) defined as the ratio of tube spacing to borehole diameter occupies the range of (0.29-0.59).

II. Present Model

Model Derivitive

The model suggests that there is a single U-tube installed in the borehole to compose a ground heat exchanger for heating or cooling heat pump system, Figure 1.

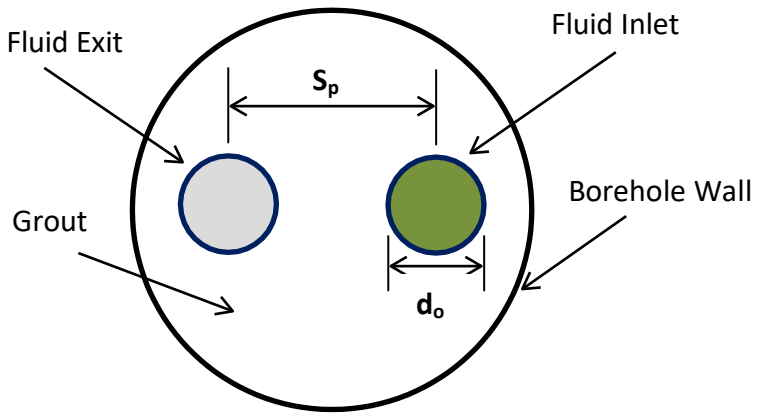

Figure 1: A schematic diagram for the proposed present model

The presentation of the thermal resistance circuit may be illustrated for the U-tube geometry, as depicted in Figure 2. A similar thermal resistance circuit was also postulated by Koenig [16] for a single U-tube ground heat exchanger.

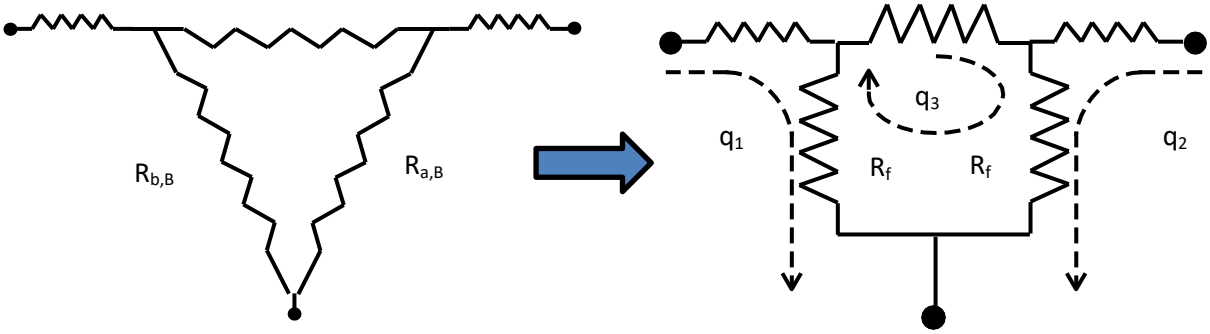

Figure 2: Analogy to electrical resistance circuit presentation of the present work

The U-tube geometry in the borehole is usually chosen to be identical, and parallel loop circuits are utilized. Hence the same fluid flows in both U-tube legs. This leads to equal tube thermal resistances on the fluid side and conduction through the tube wall for both tubes. Further for identical tube geometries, the grout thermal resistance is the same between the tube wall and the grout boundary, as illustrated on the right side of Figure 2. Therefore the following conditions hold for the present work:

$$R_{a,B} = R_{b,B} = R_f \tag{6}$$

$$R_{p,a} = R_{p,b} = R_p \tag{7}$$

$$R_p = \frac{1}{\pi\, d_i\, h} + \frac{\ln\left(\frac{d_o}{d_i}\right)}{2\,\pi\, k_p} \tag{8}$$

The following mathematical expressions are to be solved simultaneously for (q_1, q_2, and q_3).

$$\Delta T_{b,B} - (q_1 - q_3)R_f - q_1\, R_p = 0 \tag{9}$$

$$\Delta T_{a,B} - (q_2 + q_3)R_f - q_2\, R_p = 0 \tag{10}$$

$$\Delta T_{b,a} - q_3\, R_s - (q_1 - q_2)R_p = 0 \tag{11}$$

In these expressions $\Delta T_{b,B}$, $\Delta T_{a,B}$, and $\Delta T_{b,a}$ represents a temperature difference as follows:

$$\Delta T_{a,B} = T_a - T_B \tag{12.a}$$

$$\Delta T_{b,B} = T_b - T_B \tag{12.b}$$

$$\Delta T_{b,a} = T_b - T_a \tag{12.c}$$

Equations (9-11) were solved simultaneously to yield the following relations for each of heat transfer rate inside the borehole and its mutual exchange with ground and tubing systems:

$$q_1 = \frac{\Delta T_{b,B} + \varepsilon}{\beta\, R_p} \tag{13}$$

$$q_2 = \frac{\Delta T_{a,B} - \varepsilon}{\beta\, R_p} \tag{14}$$

$$q_3 = \frac{\Delta T_{b,a}\,\beta - \Delta T_{b,B} + \Delta T_{a,B}}{R_s\,\beta + 2\,R_f} \tag{15.a}$$

This expression of (q_3) can be further simplified to obtain:

$$q_3 = \left\{\frac{\Delta T_{b,a}\,(\beta - 1)}{\beta\, R_s + 2\, R_f}\right\} \tag{15.b}$$

In these expressions, the following definitions were implemented:

$$\varepsilon = R_f \left\{\frac{\Delta T_{b,a}\,\beta - \Delta T_{b,B} + \Delta T_{a,B}}{\beta\, R_s + 2\, R_f}\right\} = R_f \left\{\frac{\Delta T_{b,a}\,(\beta - 1)}{\beta\, R_s + 2\, R_f}\right\} \tag{16.a}$$

and

$$\beta = \frac{R_f + R_p}{R_p} \tag{16.b}$$

Equations (13-15) reveal that the individual values of the heat transfer rate have complex relation criteria with the parameters related to the thermal resistance of different parts of the system. Hence it is usually treated as a semi-analytical problem or a complete analytical solution with several assumptions to simplify the problems having a margin of error in their applications. The total heat transfer rate between the two legs of the U-tubing walls and borehole boundary is represented by the algebraic summation of (q_1 and q_2) as:

$$q_1 + q_2 = \frac{\Delta T_{b,B} + \Delta T_{a,B}}{\beta\, R_p} \tag{17}$$

Shunt Thermal Resistance

The thermal shunt resistance (R_s) can be modeled as an isothermal pipe to pipe conduction shape factor per unit length in an infinite medium per unit length Holman [19].

$$S = \frac{2\,\pi}{\cosh^{-1}\left\{2\left(\frac{S_p}{d_o}\right)^2 - 1\right\}} \tag{18.a}$$

$$R_s = \frac{1}{S\,k_g} = \frac{\cosh^{-1}\left\{2\left(\frac{S_p}{d_o}\right)^2 - 1\right\}}{2\,\pi\,k_g} \quad (18.b)$$

Grout Thermal Resistance

The thermal resistance of an offset tube inside a cylindrical geometry with a length to be much bigger than the radius of the tube can be deduced from the shape factor cited in Holman [19] as:

$$S_f = \frac{2\,\pi\,L}{\cosh^{-1}\left\{\frac{{D_B}^2 + {d_o}^2 - 4\,{l_p}^2}{2\,D_B\,d_o}\right\}} \quad (19.a)$$

$$R_{off} = \frac{1}{S_f\,k_g} \quad (19.b)$$

This relation possesses the same volume of tubes, grout volume, mass flow rate of fluid inside the U-tube, and the same borehole geometry. Further, the same temperature conditions around the borehole exist.

Obstruction Factor

There is a conductive borehole obstruction due to the presence of the other U-tube leg of the loop in the radial direction of heat flow. This interference or obstruction is addressed by including the factor (σ). Hence the thermal resistance between the U-tubing wall and the borehole boundary is defined as:

$$R_f = \frac{R_{off}}{\sigma} \quad (20)$$

The obstruction factor to heat transfer is effectively represented by the surface area that is shadowed by the thermal beam of one leg at an angle of (α), Figure 3.

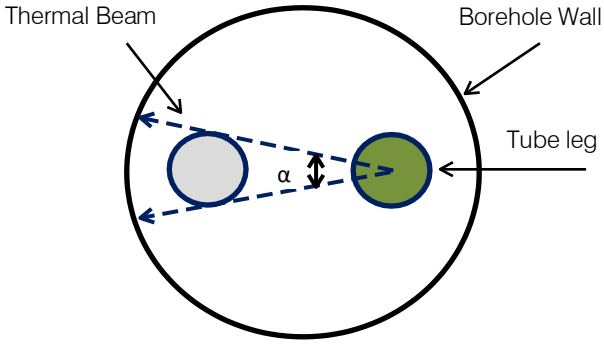

Figure 3: Thermal representation of the obstruction factor

Here, it is assumed that the heat source, the tube leg represents a line heat transfer source at the center of the tube. This is the case where heat is lost from the ground heat exchanger, and it works as a heat sink for heating purposes. The heat transfer mechanism occurs in the radial direction, and circumferential heat conduction at the borehole surface is neglected. The latter assumption implicitly states an isothermal condition at the borehole surface. The envelope behind the tube, which is projected at the borehole surface, is calculated per unit length from:

$$A_{env} = (D_B + S_p)\,\tan^{-1}\left(\frac{d_o}{2\sqrt{{S_p}^2 - \left(\frac{d_o}{2}\right)^2}}\right) \quad (21.a)$$

Simultaneously, the second leg performs the same obstruction for heat transfer, which is reflected in the total heat transfer rate in the borehole configuration. Hence, the obstruction factor can be expressed as:

$$\sigma = 1 - \frac{2\,(D_B + S_p)\,\tan^{-1}\left(\frac{d_o}{2\sqrt{{S_p}^2 - \left(\frac{d_o}{2}\right)^2}}\right)}{\pi\,D_B} \quad (21.b)$$

Equation (21) shows that the obstruction factor is only a geometry dependence parameter; its value lies in the range of ($0<\sigma\leq 1$) and depends on the borehole and U-tube configurations. The obstruction factor is equal to unity when there is no obstruction object since the thermal beam diverging angle (α) tends to zero. Hence it is always greater than zero and less or equal to (1).

This expression experiences a decrease as the two legs become closer and approaches a minimum when these tubes touch each other with ($S_p = d_e$); hence its value shows a weak dependence on the tube diameter. In other words, it produces the highest expected borehole thermal resistance for a given configuration. The obstruction factor shows a rise as the leg spacing increases and approaches the maximum as the tubes are touching the borehole surface. Hence, it showed the lowest borehole thermal resistance. However, the extreme case where the tube legs are situated along the outer surface of the borehole violates the principle assumption for heat transfer in a 1-dimensional radial direction. Accommodating the tubes at the borehole wall will create a large circumferential temperature maldistribution; the uniform borehole surface temperature assumption will be demolished.

The expression of the obstruction factor could also be confirmed by the work of Remund [20], who has reported the borehole thermal resistance for three

different cases of the two tube legs spacing. These conditions were described according to the U-tube leg spacing as, close, average, and along the outer wall of the borehole in the form:

$$R_f = \frac{1}{c_1\, k_g \left(\frac{D_B}{d_o}\right)^{C_2}} \quad (22)$$

Where the values of the coefficient (C_1) and the index (C_2) were stated for three cases, as illustrated in Table 1.

Table 1: Coefficients of equation (22), [20]

Configuration	C_1	C_2
Close together	20.10	-0.9447
Average	17.44	-0.6052
Along outer wall	21.91	-0.3796

The results of equation (22) revealed that for a given borehole configuration as the tube legs get closer, the borehole thermal resistance showed a rise and approached maximum as they touch each other. It approaches a minimum value as the tube spacing reaches a maximum as the tubes touch the borehole surface. Further, Gu and O'Neal [14] in their work for replacement of the U-tube by equivalent concentric tube at the borehole had arrived at the same conclusion. Increasing the two legs spacing results in an increase of the equivalent diameter and in turn, reduces the grout and borehole thermal resistance.

These results are consistent with the present work outcomes for the obstruction factor (σ), and its numerical value is a geometrical parameter only regardless of the operating conditions.

Borehole Thermal Resistance

The thermal resistances of different sources inside the borehole to heat transfer between the fluid flow in the tubes as a heat source or sink, and the borehole boundary are presented in eq. (8) and eq. (20). Therefore, the total borehole resistance is expressed by:

$$R_B = R_p + R_f \quad (23)$$

Equation (14) can be simplified further to give:

$$q_1 + q_2 = \frac{T_b + T_a - 2\,T_B}{\beta\, R_p} \quad (24.a)$$

The net total heat transfer rate that crosses the boundary of the borehole is expressed as:

$$q_1 + q_2 - q_{env} = \frac{\Delta T_m}{R_B} = \frac{(T_m - T_B)}{R_B} \quad (24.b)$$

In eq. (24.b) the mean temperature of the fluid inside the tubes is considered as:

$$T_m = \frac{(T_a + T_b)}{2} \quad (24.c)$$

and

$$q_{env} = (q_1 + q_2)\,(1 - \sigma) \quad (24.d)$$

Combining eq. (24.a) and eq. (24.b) yields to:

$$R_B = \frac{\beta\, R_p}{2\,\sigma} \quad (25.a)$$

Hence the borehole thermal resistance corresponds to:

$$R_B = \frac{R_p + R_f}{2\,\sigma} \quad (25.b)$$

When the obstruction factor is dismissed, then (σ) is equal to unity, and the same expression will be obtained as that of Koenig [16].

An interesting result may be deduced from the present analysis when it is applied for geothermal DX evaporators and condensers. The change of phase usually takes place in an isothermal ($T_b = T_a = T$) process for pure refrigerants, nonazeotrop mixtures and azeotropic mixtures of the negligible boiling range such as R-410A, then:

$$q_1 = q_2 \quad (26)$$

$$q_1 + q_2 - q_{env} = \frac{2\,(T - T_B)}{\beta\, R_p} \quad (27)$$

Further, the heat transfer rate (q_3) as presented in eq. (15.b) approaches zero and eq. (25) is still applicable.

Ground Thermal resistance

The ground thermal resistance is important for the assessment of heat transfer rate and temperature distribution of the ground heat exchanger. Garbai and Méhes [21] have included the effect of the ground as a resistance to heat transfer from or to the U-tube fluid for a region extended to infinity. They have concluded that after (1) year of operation, the heat transfer process approaches steady-state conditions and the value of (0.053) m.K/W for a ground thermal conductivity of (2.42) W/m.K was estimated. Hence, it was decided to implement this value at the present work.

Total Thermal Resistance

The total thermal resistance per unit length of the borehole is estimated by:

$$R_t = R_B + R_{ground} \quad (28)$$

This expression represents the thermal resistance of the double U-tube GHE to heat transfer.

III. Verification Methodology

Ground Heat Exchanger Specifications

The verification of the model was accomplished by the comparison with previously published correlations in the open literature. The following conditions were utilized for a hypothetical heat pump system utilizes the U-tube GHE:

1. A heat pump coupled ground heat exchanger is utilized for cooling purpose having the following operating conditions:
   - Cooling load of (3.5) kW to be extracted from the space throughout the circulation of chilled water in fan coils installed at the required points.
   - Chilled water to be produced by circulating through the chiller at a temperature range of (7-12) °C.
   - Rejected load to the ground by the copper tubing of the condenser was estimated in the range of (4.4) kW with COP of (3.57) for cooling.
2. A single copper U-tube and borehole dimensions are shown in Table 2.

Table 2: Selected geometrical configurations for a single U-tube

Geom.	d_o (mm)	D_B (mm)	S_p/d_o (-)	S_p/D_B (-)	Gref (kg/m² s)	V_{ref} (m/s)		AU-tube (m²/m)
						Vap	Liq.	
1	9.525	65	2-4	0.29-0.59	371.43	5.03	0.364	0.05985
2	12.7	75	2-3.3	0.34-0.56	199.27	2.7	0.196	0.0798

3. The borehole is filled with grout, having a thermal conductivity range between (0.73) W/m.K and (1.9) W/m.K, [22].
4. R-410A is circulated through the heat pump in the DX system. It has a typical condensation heat transfer coefficient of (3000) W/m² K, Huang et al. [23] and Kim and Shin (2005) [24]

The mass flux density and fluid flow velocity were calculated from:

$$G_{ref} = \frac{\dot{m}_{ref}}{A_{c,i}} \quad (29.a)$$

$$V_{ref} = \frac{G_{ref}}{\rho_{ref}} \quad (29.b)$$

Maximum U-tube Spacing

The tube spacing (Sp) was selected according to the relation given by Koenig [16] for practical applications of the ground U-tube heat exchanger as follows:

$$D_s + 2\,d_o \le 0.75\,D_B \quad (30)$$

Rearranging this relation in terms of the tube spacing (Sp) gives:

$$S_p + d_o \le 0.75\,D_B \quad (31)$$

This expression shows that the maximum tube spacing inside the borehole is controlled by:

$$S_{p,max} = 0.75\,D_B - d_o \quad (32)$$

IV. Results and Discussion

Grout Thermal Resistance

The present work results of the thermal resistance of grout are compared to other available correlations in the open literature. The single loop borehole specific thermal resistance for the WF of (14.29) geometry is compared in Figure 4.

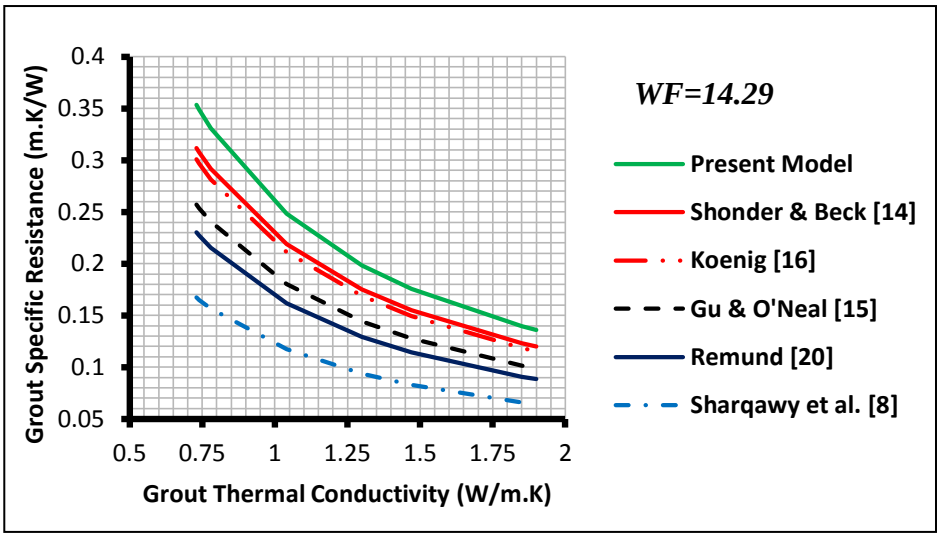

Figure 4: Comparison of different grout thermal resistance expressions for the test WF=14.29 geometries at (S_p/ d_o=3.3)

The data revealed that the present model predicted higher grout thermal resistance than other investigators. It was higher than that of the closest data of Shonder and Beck [14] by about (15) %. Sharqawy et al. [8] prediction was the lowest among other correlations and the rest occupies the zone in between the two mentioned models. The thermal resistance predicted by Koenig [16] and Shonder and beck were close to each other and were higher than those of Gu and O'Neal [15] and Remund [20]. As the grout thermal conductivity increases, the predicted results are getting closer and approaching a minimum discrepancy at the highest tested thermal conductivity of (1.9) W/m.K. This is due to the decrease of thermal resistance of the grout as the thermal conductivity increases, eq. (19).

At a constant value of (S_p / D_B), the thermal resistance showed dependence on the grout thermal conductivity in the form:

$$R_B = \beta_0 \, k_g{}^{\beta_1} \tag{33}$$

The index (β_1) has a negative value. A linear behavior for the borehole thermal resistance with the ratio (S_p / D_B) at constant grout thermal conductivity is obvious in Figure 5 for both geometries. It was a steeper for the bigger tube size (12.7) mm outside diameter than that of the smaller one of (9.52) mm. This, of course, is related directly to the thermal resistance of the grout layer that covers these tubes; the lower thermal resistance corresponds to the steeper line variation in Figure 5.

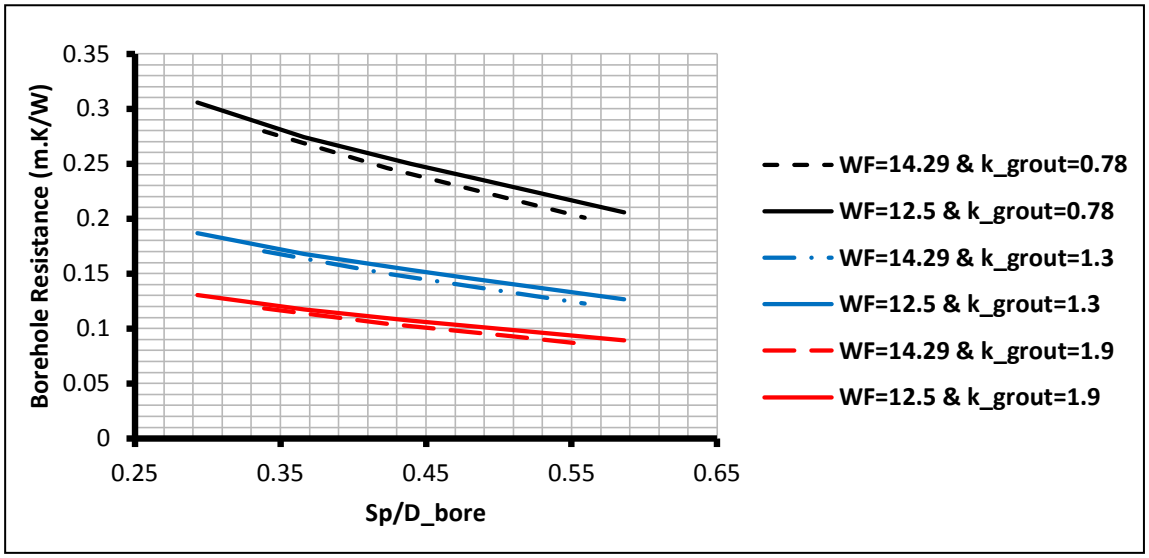

Figure 5: A comparison for the variation of borehole thermal resistance with (ζ) at different grout thermal conductivity

Grout Thermal Conductivity

The thermal resistance showed a reduction with thermal conductivity increase regardless of the (ζ) ratio value and exhibited the lower at the higher test grout thermal conductivity. The trend of the data may be presented in a linear formula as:

$$R_B = a_0 + a_1 \left(\frac{S_p}{D_B}\right) \tag{34}$$

The coefficient (a_0) is a negative value. These results were also confirmed by Koenig [16] and Gu and O'Neal [15] work. The borehole resistance revealed a declination with the geometry factor (ζ) increase. Increasing of the geometry factor refers to the increase of the U-tube spacing (S_p) of the tube legs. Hence, the thermal resistance decreases as the distance of the two tubes increases. The lower grout thermal conductivity of (0.78) W/m.K showed a higher value for (R_B) and exhibited a steeper gradient with the geometry factor (S_p/D_B). As the grout thermal conductivity increases, it produces a lower (R_B) level and flatter curve representation. The latter is mainly due to the decrease of the temperature gradient with (k_g) increase and hence improves the heat transfer inside the borehole body.

Borehole Thermal Resistance

Figure 6 depicts the comparison of the borehole thermal resistance of various models for two configurations.

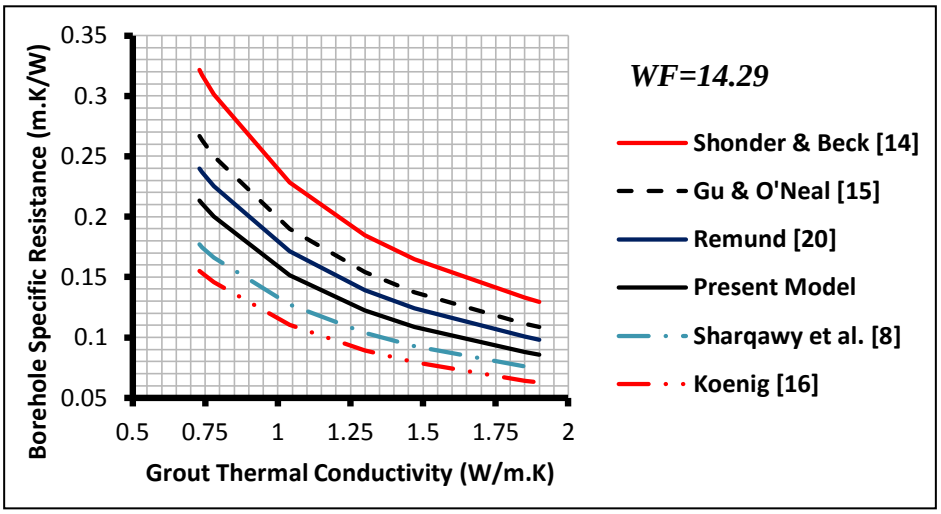

Figure 6.a: Borehole thermal resistance at WF=14.29

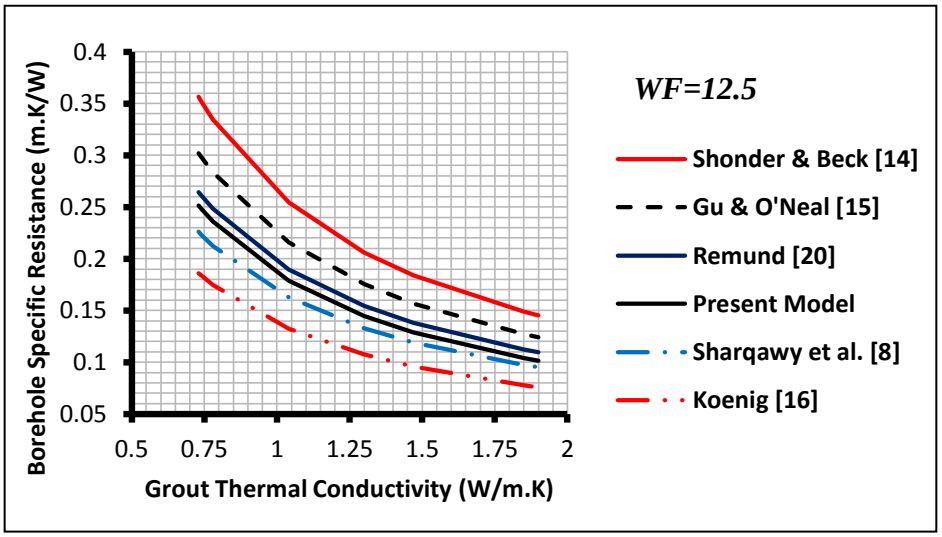

Figure 6.b: Borehole thermal resistance at WF=12.5

Figure 6: Comparison of different borehole thermal resistance expressions for the test single loop geometries at ($S_p/d_o=3.3$)

The present model showed a similar trend of data to those of other investigators, and it is located closer to that of Remund [20] and Sharqawy et al. [8] ones for both tested configurations. Koenig [16] expression revealed the lowest resistance value and Shonder and Beck [14] showed the highest values among other correlations; it was about double of that of the earlier investigator. Shonder and Beck [14] have replaced the two legs of the U-tube by an equivalent tube diameter concentric at the borehole; this procedure loses a surface area for the U-tube by about (30) % per unit length. Hence, it will exhibit higher thermal resistance, or it needs more surface area to accomplish the same heat load. The same dialogue is true for Gu and O'Neal [15] correlation because a similar technique was implemented to build up their model. The response of the present work for a single loop GHE to the variation of the geometrical configuration is present, as shown above. It is also predicted reasonable values for the borehole thermal resistance when compared with other available correlations.

U-Tube Size

A comparison of the predicted borehole thermal resistance by the present model for the single loop of the four geometries is illustrated in Figure 7. The thermal resistance showed a decrease as the U-tube diameter increases, and it is also showed a declination as the grout thermal conductivity increases.

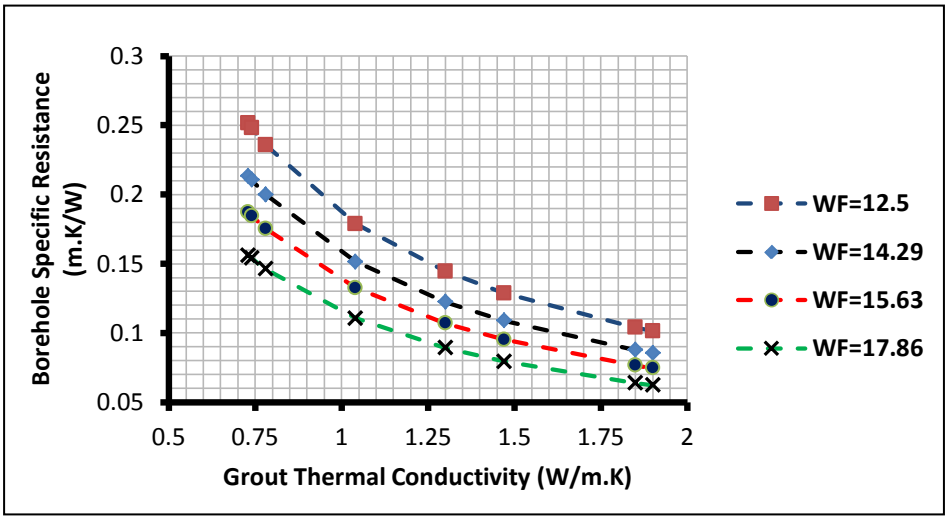

Figure 7: A comparison for the borehole thermal resistance of different configurations at (S_p / d_o=3.3)

The bigger tube size with WF of (17.86) possesses the lowest borehole thermal resistance, among other tested sizes. Whereas, the smaller tube size having a WF of (12.5) revealed the highest thermal resistance. This is related directly to the thickness of the grout layer, which covers these tubes. The bigger thickness reveals higher thermal resistance and vice versa. Also, the bigger tube size possesses a larger surface area per unit length and hence increases the heat transfer rate in the borehole. The smaller tube size of (9.52) mm outside diameter showed a higher thermal resistance by (66.7) % and (39) % than those of (19.05) mm diameter at grout thermal conductivity of (0.73) W/m.K and (1.9) W/m.K respectively. The other tested U-tube sizes occupied the zone bounded by these two tube configurations. This phenomenon was also confirmed by other investigators presented in this work.

U-Tube Legs Spacing

The center to center U-tube legs spacing is of vital importance in the process of heat transfer inside the borehole and U-tube configuration system. It has been found that the ground heat exchanger depth is proportional to the total borehole thermal resistance and hence the spacing of its tube legs [15, 16, and 20]. The present model was investigated for the verification of the ratio of tube spacing to the borehole diameter (S_p / D_B). Figure 8 illustrates a comparison for the borehole thermal resistance obtained at different values of the ratio of (S_p / D_B) in the range of (0.29) and (0.59) for both geometries.

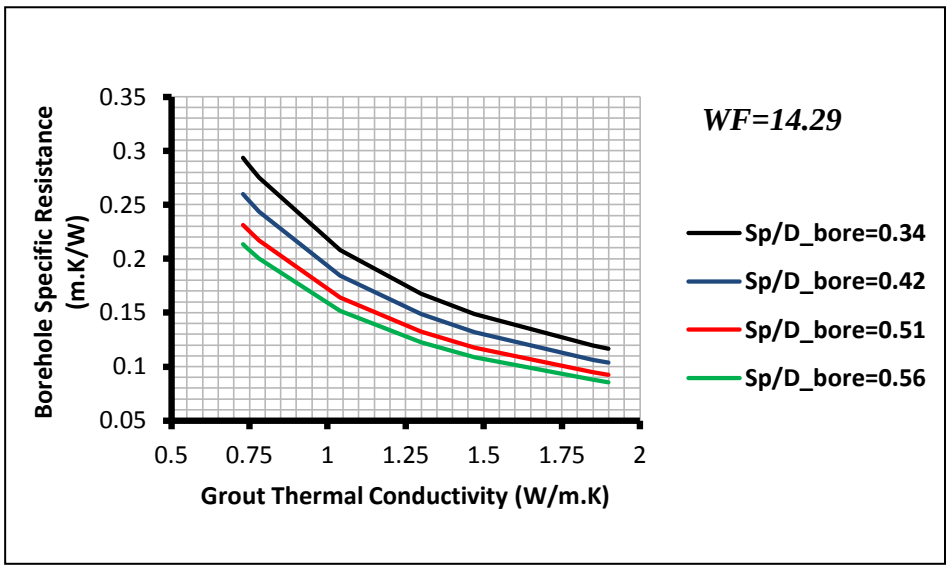

Figure 8.a: A comparison at WF=14.29

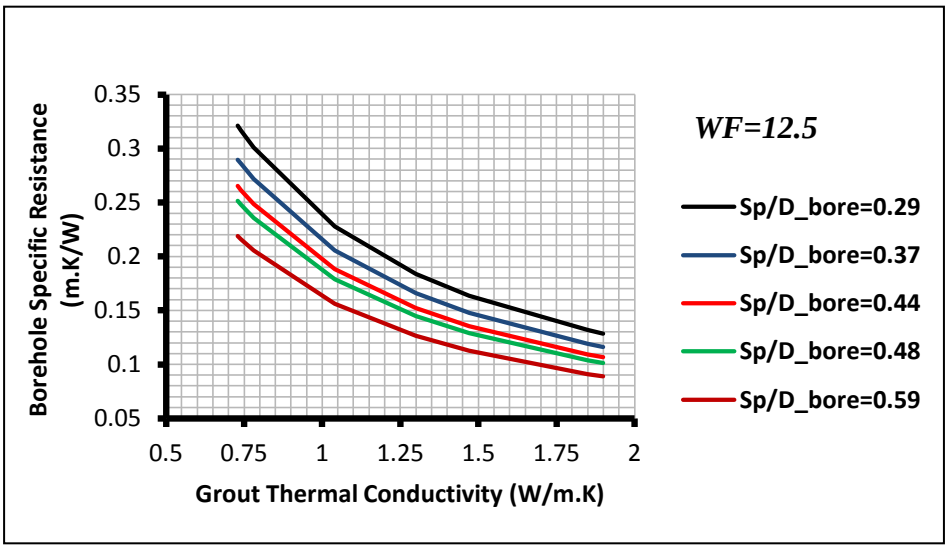

Figure 8.b: A comparison at WF=12.5

Figure 8: A comparison for the present model prediction of borehole thermal resistance for different configurations at various (S_p / D_B)

As the geometry factor (ζ) increases, the spacing between the U-tube legs is also increasing and hence revealed a lower borehole thermal resistance. Similar behavior is noticed for both geometries regardless of the U-tube borehole configurations. These results revealed consistency with other investigators who have studied this factor, Gu and O'Neal [15], Koenig [16], Garbai and Méhes [21], and Remund [20]. It is clear that the borehole thermal resistance of a GHE is a function of the ratio (S_p / D_B) and grout thermal conductivity, Figure 8. The present work showed that when increasing (S_p / d_o) ratio from (2) to (3.3) for both tube wall factors showed a decrease in the borehole thermal resistance. The predicted borehole thermal resistance at (S_p / d_o) of (2) was higher than that of (3.3) by the range of (22-54) % and (26.5-28) % at wall factor of (12.5) and (14.29) respectively for the examined range of grout thermal conductivity.

Total Borehole Thermal resistance

The total thermal resistance between the fluid and soil region is compared for various correlations is illustrated in Figure 9.

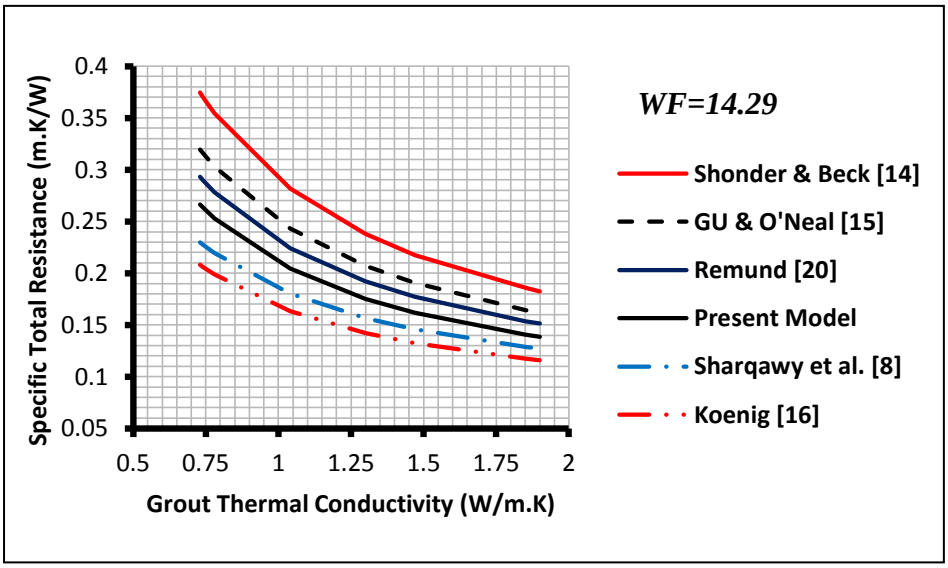

Figure 9.a: A comparison at WF=14.29

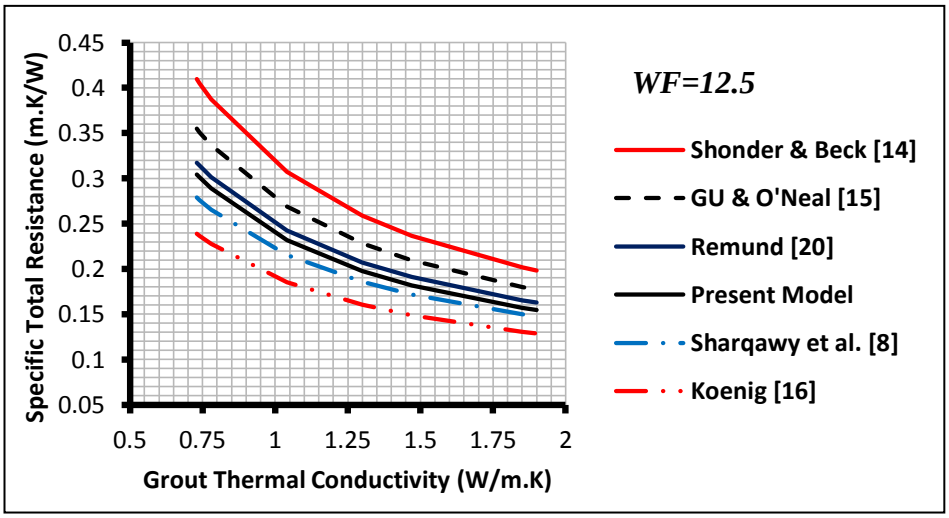

Figure 9.b: A comparison at WF=12.5

Figure 9: Comparison of different total borehole thermal resistance expressions for the test single loop geometries at (S_p / d_o=3.3)

The same trend can be inferred from all of the examined correlations for both borehole configurations. The trend of the curves and predicted values are similar to those of borehole thermal resistance in their distributions for all of the correlations presented in this graph. The Shonder and Beck [14] correlation showed the highest level among other models, and the Koenig [16] model revealed the lowest. As the grout thermal conductivity increases, the curves are getting closer to each other due to the decrease in the temperature gradient and reduced borehole thermal resistance. The present model predicted a moderate values and are closer to Remund [20] predictions than other test correlations.

Heat Loading

The comparison of predict heat loading per unit length of the U-tube heat exchanger is presented in figure 10 for both investigated configuration.

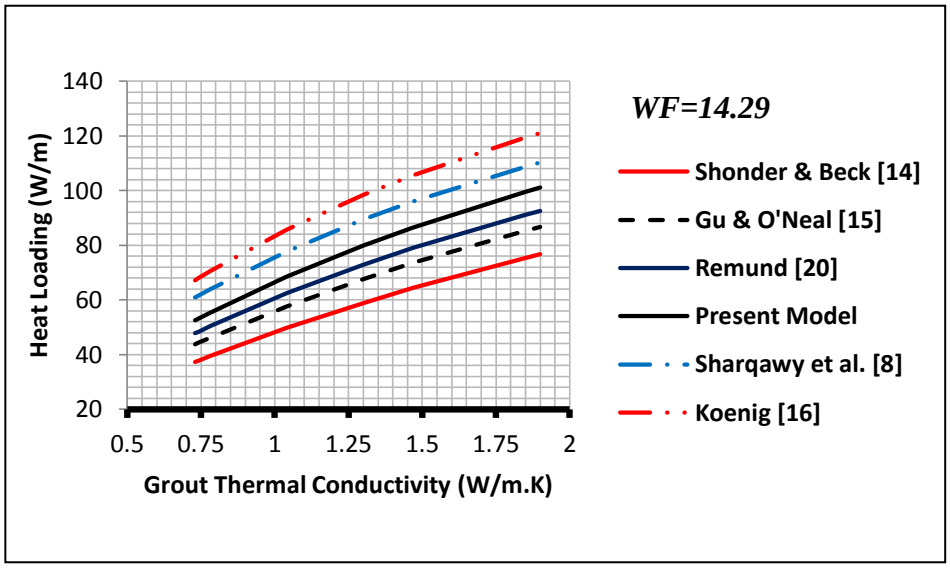

Figure 10.a: A comparison at WF=14.29

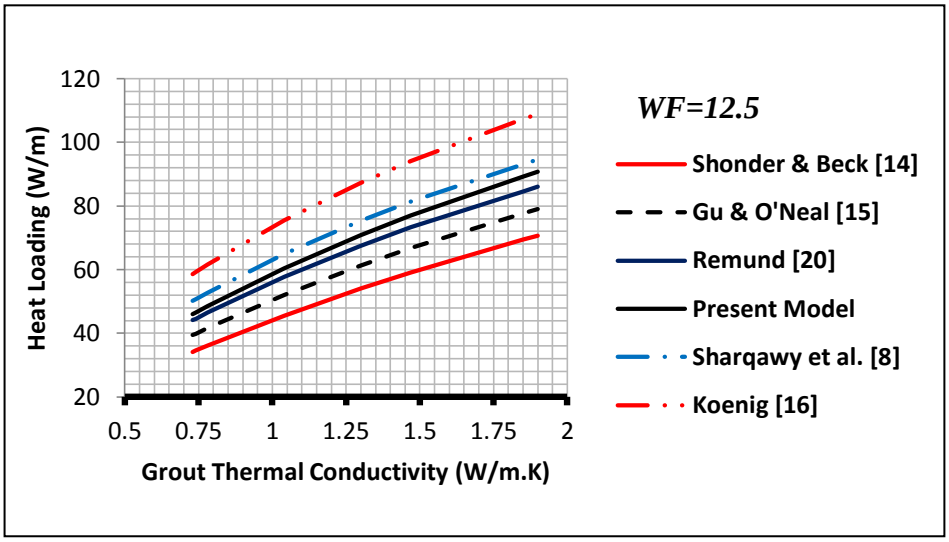

Figure 10.b: A comparison at WF=12.5

Figure 10: Comparison of different borehole heat loading expressions for the test single loop geometries at (S_p / d_o=3.3)

Although the underground temperature is almost stable over the year-round it is also a dependent measure on the altitude. The temperature in the ground below (6) m is roughly equal to the mean annular air temperature at that altitude. It is at the range of (10-16) °C. Seasonal variation decreases with depth and disappears below (7 to 12) m, Tarrad [25]. Hence to construct the objectives of performing the heat loading calculation, a temperature difference between the refrigerant and ground of (14) °C was utilized. It was calculated from the conduction heat transfer relation in the form:

$$q = \frac{\Delta T_m}{R_t} \tag{35}$$

The predicted specific heat loading for the bigger tube size (12.7) mm outside diameter was higher than that of the smaller tube size (9.52) mm for all of the examined correlations and had similar data trends. Koenig [16] model predicted the higher heat loading of the GHE; it was in the range of (68-120) and (60-110) W/m for WF values of (14.29) and (12.5) respectively. Shonder and Beck [14] correlation produced the lower level for both geometries; the numerical values were in the range of (38-77) W/m and (35-70) W/m at WF of (14.29) and (12.5) respectively. The present model revealed a moderate heat loading, among other investigated correlations, regardless of the U-tube size. The respective numerical values at WF of (14.29) and (12.5) were (53-101) W/m and (47-90) W/m. These values of heat loading are almost occupying the midway zone between Koenig [16] and Shonder and Beck [14] correlations. Sharqawy et al. [8] and Remund [20] predicted heat loadings higher and lower than those of the present work respectively.

Koenig [16] model predicts the lowest borehole depth, whereas the Shonder and Beck [14] correlation produces the deepest borehole. This is because the predicted total thermal resistance of the borehole/ground for Shonder and Beck was higher than those of Koenig [16] and other models, including the present work, as illustrated in Figure 9. The correlations presented by Shonder and Beck [14] and that of Remund [20] have no response to the ratio (S_p / d_o). Hence they are expected to predict constant values of the depth regardless of the tube spacing for a given configuration. The present model showed an interaction response to the tube spacing variation as those of Koenig [16], Sharqawy et al. [8], and Gu and O'Neal [15] models. Further, the present model predicted almost a mean value for those of Shonder and Beck [14] and Koenig [16].

V. Conclusion

An analytical model was performed to formulate a thermal analysis for a single U-tube ground source coupled heat pump. An obstruction factor to heat transfer in the borehole configuration was addressed and implemented in the present model. Consistence of the borehole thermal resistance behavior with different geometry factors existed with previously published work in the open literature. The borehole thermal resistance of the U-tube showed a decrease with tube diameter and grout thermal conductivity increase. The borehole thermal resistance decreases with the geometry factor (ζ) increase and approaching a minimum as the two legs of the U-tube are located close to the borehole surface. Increasing of (S_p / d_o) ratio from (2) to (3.3) for

both tube wall factors showed a decrease in the borehole thermal resistance. The predicted borehole thermal resistance at (S_p/ d_o) of (2) was higher than that of (3.3) by the range of (22-54) % and (26.5-28) % at wall factor of (12.5) and (14.29) respectively for the examined range of grout thermal conductivity. The results showed that the predicted heat loading of the heat exchanger at (S_p/ d_o) of (3.3) and (ΔT_m) of (14) °C, was ranged between (46-53) W/m and (91-101) W/m as predicted at (0.73) W/m.K and (1.9) W/m.K grout thermal conductivity respectively. The model could be improved to allow the implementation of different tube sizes for the U-tube legs, which is the usual case for DX ground condensers and evaporators.

Nomenclature

Parameter	Definition
a_0	Coefficient in eq. (34)
a_1	Coefficient in eq. (34)
A	Tube area, m^2
COP	Coefficient of performance
d	Tube diameter, m
D	Borehole diameter, m
G	Mass flux density, kg/m^2 s
GHE	Ground heat exchanger
h	Convection heat transfer coefficient, W/m^2 K
k	Thermal conductivity, W/m.K
L	Length, m
l_p	Tube offset length, m
$\dot{m}$	Mass flow rate, kg/s
q	Heat transfer rate per unit length, W/m
$\dot{Q}$	Heat transfer rate, W
R	Thermal resistance per unit length, m.K/W
S	Geometry shape factor, m
S_p	Tube legs spacing, m
t	Thickness, m
T	Fluid or wall temperature, K
ΔT	Temperature difference, K
V	Fluid velocity, m/s
WF	Wall factor=d_o/t

Subscribes

a	Tube (a)
b	Tube (b)
B	Borehole
c	Cross sectional
$cond$	Condenser
e	Equivalent
env	Envelop
f	Filling
g	Grout
i	Inside
m	Mean
max	Maximum value
o	Outside
off	Offset tube value
p	Pipe
ref	Refrigerant
s	Shunt
t	Total

Greek Letters

α	Thermal beam diverging angle
β	Equivalency coefficient
β_0	Coefficient in eq. (33)
β_1	Index in eq. (33)
ε	Parameter defined in eq. (16.a)
ζ	Geometry factor
ρ	Refrigerant density, kg/m^3
σ	Obstruction factor defined in eq. (21.b)

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Characteristics and Performance of Vertical-Axis Wind Turbine (VAWT)

By Yongjian Gu

Abstract- There are two technologies of wind turbines. One is the horizontal-axis wind turbine (HAWT), which dominates the market of wind farms since the HAWT has a higher energy transfer efficiency. Another is the vertical-axis wind turbine (VAWT), which has unique characteristics to be able to compete with the HAWT, especially in application locations. This paper first introduces the working mechanism of the VAWT and presents different types of VAWTs. Then the paper lists the major difference between VAWTs and HAVTs. It is attractive that the VAWT doesn't need long length blades and a giant tower so that the VAWT doesn't require a large open area and can be applied in the areas of metropolitan, community, and resident. In these areas, VAWTs not only can efficiently utilize wind energy but also may have cosmetic effects for the buildings and surroundings. The paper reveals the unique characteristics of the VAWT: replaceable and stackable. The replaceable feature allows an existing VAWT to be altered to a different VAWT type amazingly and the stackable feature lets the VAWT be upgraded conveniently to meet the load requirements. In the paper, the author presents a novel design of the stackable VAWT, a green power tower (GPT).

Keywords: *wind energy, vertical-axis wind turbine (VAWT).*

GJRE-J Classification: *FOR Code: 091199*

Strictly as per the compliance and regulations of:

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Keywords: wind energy, vertical-axis wind turbine (VAWT).

I. Introduction

A wind turbine is a device converting wind energy into useful power. There are two technologies of wind turbines: horizontal-axis wind turbine (HAWT) and vertical –axis wind turbine (VAWT). In a HAWT, the turbine shaft axis is parallel with the ground. While in a VAWT, the turbine shaft axis is perpendicular to the ground. Both turbines are shown in Figure 1.

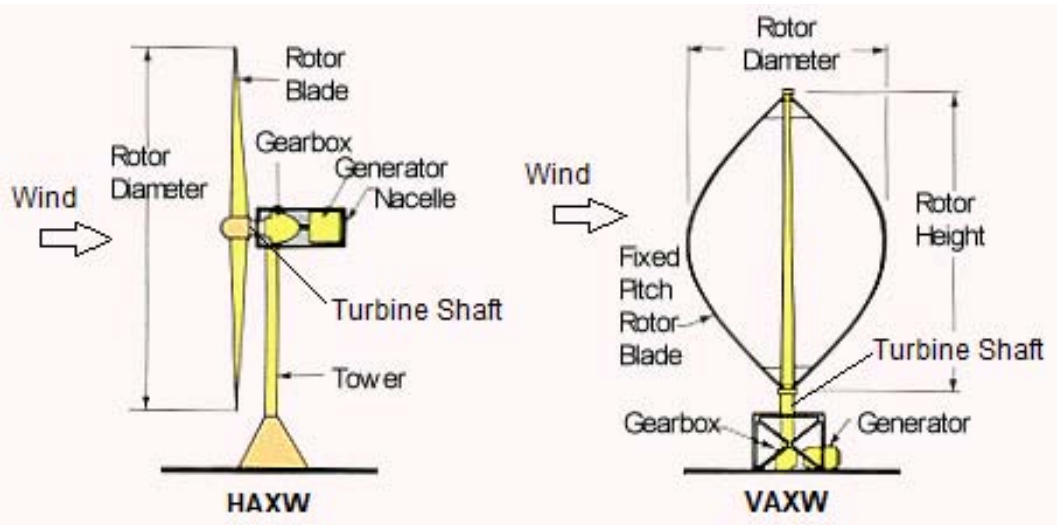

Fig. 1: HAWTs and VAWTs

In wind farm application, HAWTs are more popular than VAWTs since HAWTs have higher efficiency for the unit wind energy utilizationthan VAWTs. The working mechanism of two, nevertheless, HAWTs and VAWTs is the same - wind blowing the wind turbine blades converts the kinetic energy of the wind to mechanical energy (wind turbine shaft work). Then the wind turbine shaft drives a generator to convert the mechanical energy to electrical energy. Figure 2 illustrated the working principle of the VAWT.

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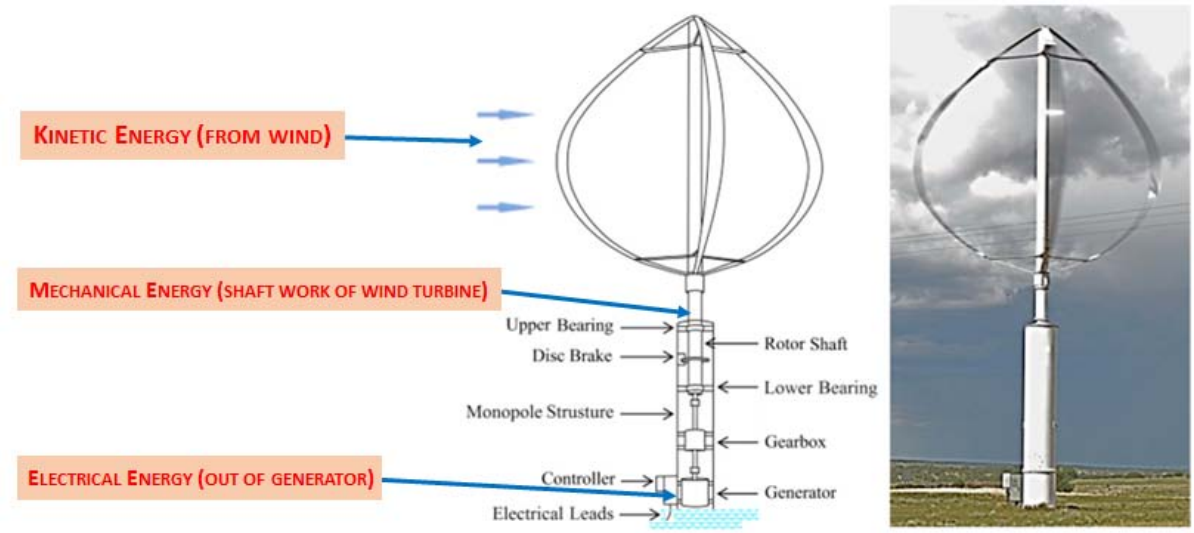

Fig. 2: Working Principle of VAWTs

In wind turbine history, the first wind turbine was VAWT dated back to the Egyptian civilization, where it was used in sailboats. In wind turbine development, various VAWT were designed. Figure 3 presents some of the VAWTs.

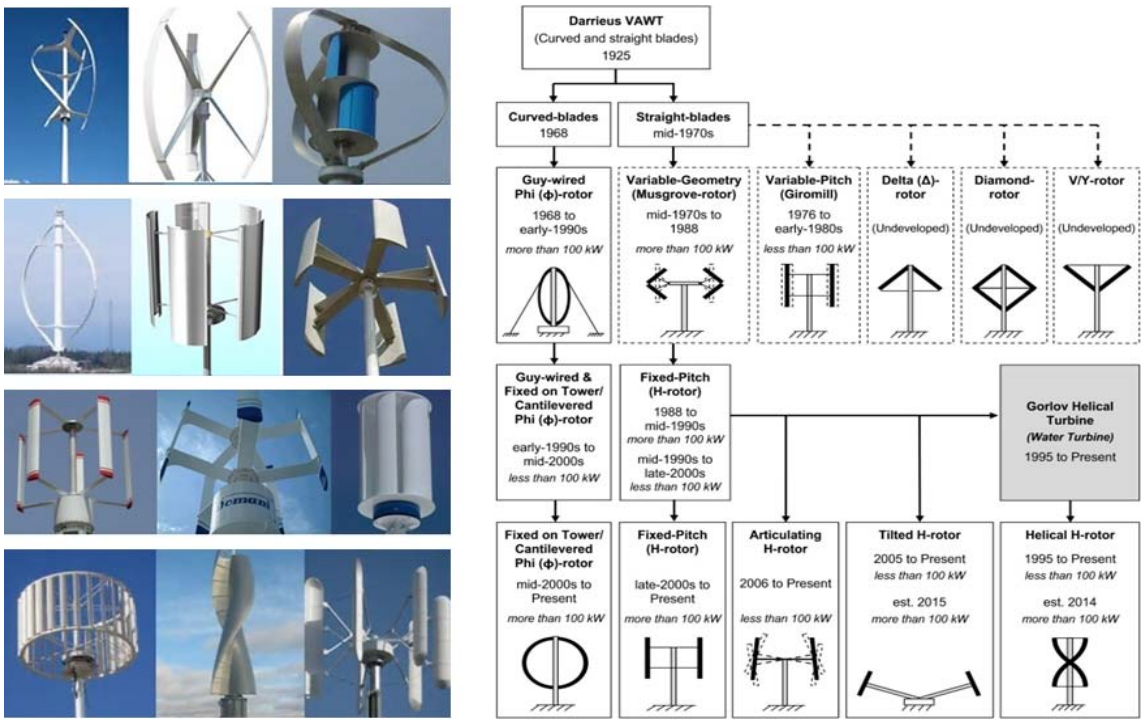

Fig. 3: Different VAWT designs

II. Difference Between HAWTs and VAWTs

Except the difference of the wind flow direction with the shaft axis, HAWTs and VAWTs have some differences and impacts in construction, economy, and environment. In HAWTs, the huge towers and large blades result in a high cost and trouble in the environment. After several decade of developments, HAWTs are becoming the bigger and the taller. The huge HAWTs are not suitable to locate in the areas of metropolitan, community, and resident, etc. Therefore, VAWTs become more attractive and practical in such areas. VAWTs are more convenient for installation and maintenance in which the electric system is on the ground. A summary of major differences between HAWTs and VAWTs are shown in Table 1.

III. Advantages of VAWTs

From Table 1, it can be seen that HAWTs have advantages of efficiency and commercial availability; VAWTs, however, have the advantages which can compete with HAWTs, in application location, environment effect, etc.

Table 1: Major Difference between HAWTs and VAWTs

FACTOR	VAWT	HWAT
Power Generation Efficiency	50-60%. Less wind flow usage and partial blades are in operation	>70%. More wind flow usage and all brades are in operation. Less aerodynamic loss.
Blade Ratotion Speed	Quite Small. Lower weight of the blade.	Quite Large. Heavy weight of the blade.
Vibration Levels	Low. Symmetricity to the shaft.	High. Heavy blades on one end of the shaft.
Noise	0-10db. Due to low vibration level.	5-60db. Due to high vibration level.
Required Wind Speed	Fair. Because of the lower weight of the blades.	Strong. Because of the haveay weight of the blades.
Starting Wind Speed	Fair. Because of the lower weight of the blades.	Strong. Because of the haveay weight of the blades.
Wind Direction	No Effect. Can operate with wind from any direction.	Sensible. Has to turn around and fact to the wind direction
Effect on Enviroment	Small. Rotation area is small. Lower noise.	Large. Rotation Area is huge. Higher noise. There is design and manufacture standard. Their height makes them obtrusively visible across large areas, disruption the appearance of the landscape.
Commercial Availablility	Low. Has no standard.	High.
Installation Cost	Low. Major equipment is near ground.	High. Major equipment is on the tall tower. Massive towre construction is required to support the neary blades, gearbox, and generator. Tall tower are difficult to install, needing very tall and espernsive cranes, and skilled operation.
Maintenance Cost	Low. Major equipment is near ground.	High. Major equipment is on the tall tower.
Transportation Cost	Low. Small size of tower and blades.	High. Giant size of tower and blades. The tall towers and blades up to 90 meters long are difficult to transport. Transportation can be 20% of equipment costs.
Wind Farm Application	Few. Since efficiency is lower.	More. High efficiency is more attractive.

Figure 4 shows some locations and areas being suitable for VAWTs application. In 2010, two VAWTs were successfully installed on the Eiffel Tower, Paris, shown in Figure 5. They were installed 400 feet up on the 2nd tower level and provided 10,000 kWh of green electricity each year. It was an iconic application of the VAWT.

Roadside/ Express Way Tunnel/ Bridge Building/ Residence Area

Fig. 4: Locations and Areas of VAWTs Application

Fig. 5: Two VAWTs on Eiffel Tower in Paris

IV. Characteristics of VAWTs

Most of VAWTs have unique characteristics: replaceable and stackable. The replaceable characteristic allows an existing VAWT to be altered to another type amazingly and the stackable characteristic lets the VAWT be upgraded conveniently to meet the load requirements. Figures 6 and 7 illustrate the two characteristics, respectively.

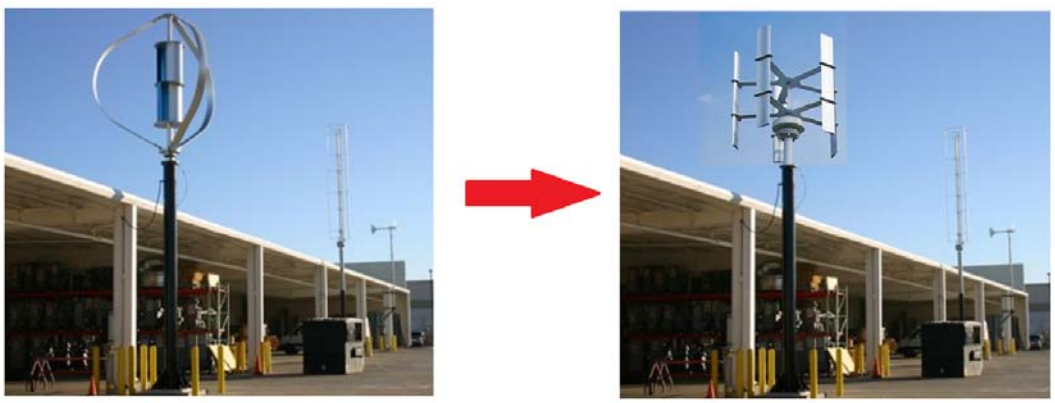

Fig. 6: Replaceable Characteristic of VAWTs

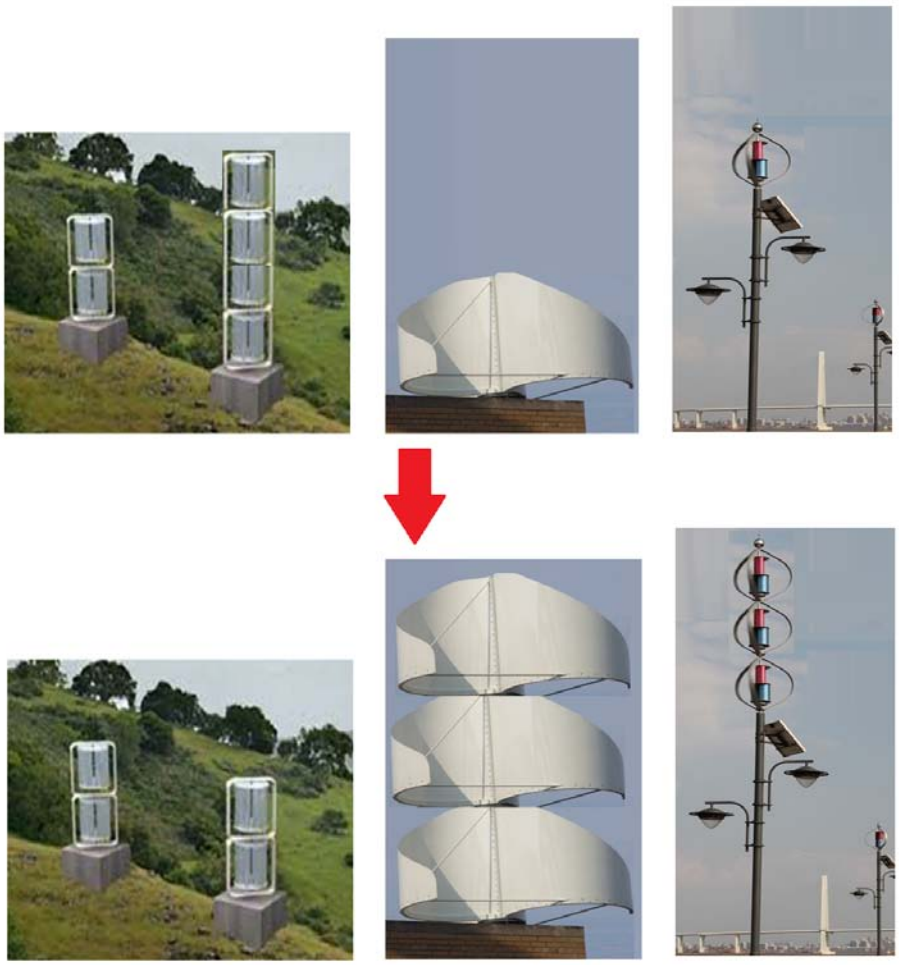

Fig. 7: Stackable Characteristic of VAWTs

V. A Novel Design of VAWT

Green power tower (GPT), a novel VAWT design, is developed. The GPT is a stackable type and has no exposed rotating components.

a) Working Principle

Figure 8 shows the configuration of the GPT. Air stream horizontally blows into the channels to drive the shaft by rotating turbine blades. The air stream will flow out on the top of the GPT. The GPT is packable and can have multiple levels to meet the power requirement. The shaft at the tower center drives the electric generator on the bottom.

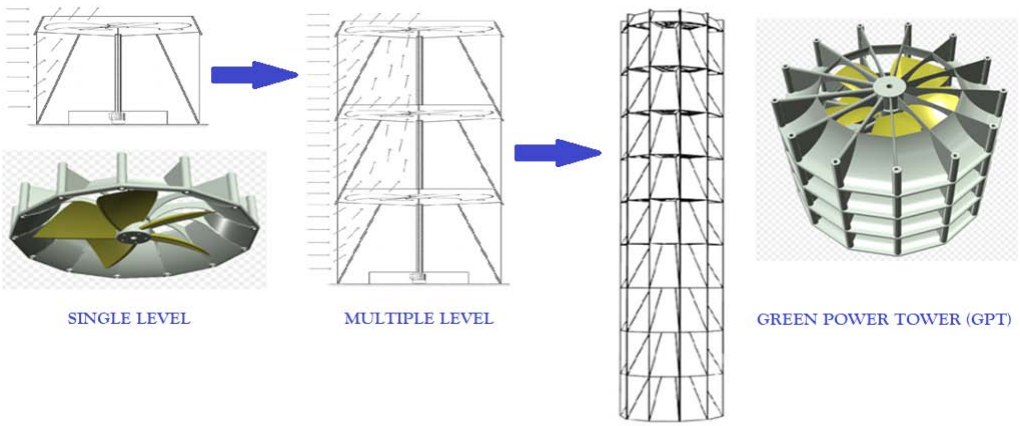

Fig. 8: Green Power Tower (GPT)

b) GPT Performance Test

To evaluate the performance of the GPT, the scaled prototypes were built and tested with different wind blades. Figure 9 presents the tests conducted in the wind tunnel and at the site, respectively. At the site tests, the GPT was installed on the top of the moving vehicle. The driving speed of the vehicle is the velocity of the wind blowing.

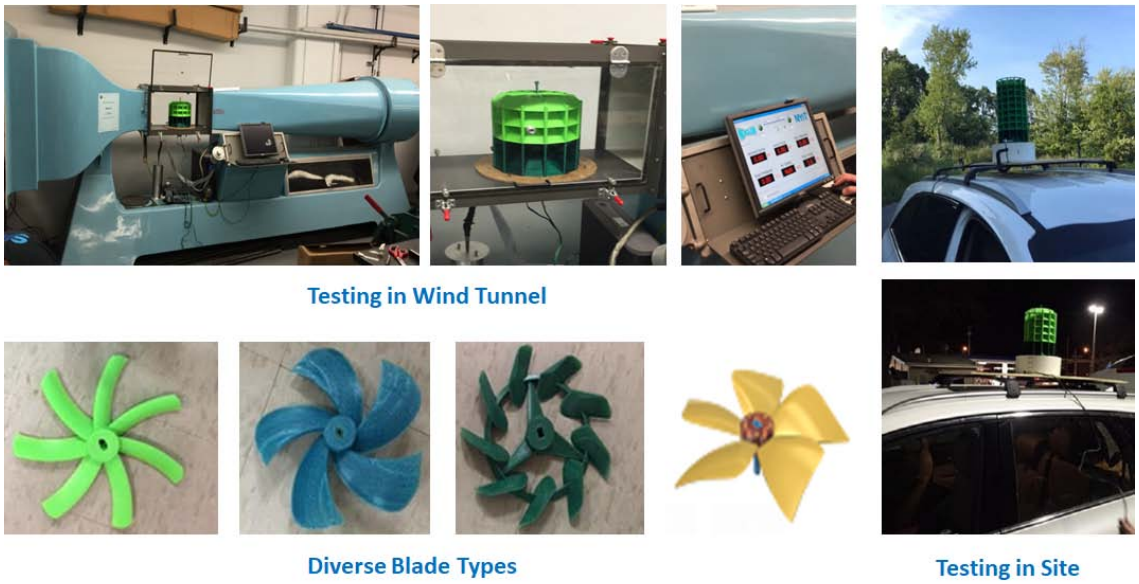

Fig. 9: Performance Testing

The GPT can be stacked to have multiple levels. In the tests, one, two, and three levels of GPTs were conducted to see the power generation capacity, tip speed ratio *TSR*, and power coefficient $C_p$of level impacts. *TSR* and $C_p$are defined by, respectively

$$TSR = \text{tip speed of blade/wind speed} = (2\pi r \times RPM)/60v \quad (1)$$

Where r – radius of wind blade (distance from wind shaft axis center to blade tip) (m)
RPM –are volution in per minute of wind blade
v – wind speed (m/s)

$$C_p = P_{out}/P_{in} = (Vx\ I)/P_{in} \quad (2)$$

Where P_{out} – power output from a wind turbine (kW)
P_{in}–thepower of the wind (kW), $P_{in} = \rho\pi d^2v^3/8$
P – density of air (kg/m^3)
d – diameter of wind turbine (m)
V – electrical voltage generated by a wind turbine(V)
I – electrical current generated by a wind turbine (A)

In the test, both V and I were measured by a multimeter, respectively.

c) Testing Results and Discussion

The tests were performed for both GPT and HAWT for comparison. The prototype data are listed in the following Table 2.

Table 2: Prototype Data in Test

Prototype	Radius (i.e., length of blade) (cm)	Swept Area (cm^2)
GPT- 1(One level)	9	255
GPT- 2(Two levels)	9	509
GPT- 3 (Three levels)	9	763
HAWT-1	12	450
HAWT-2	13	530

Test results of GPT performance and comparison are shown in Figure 10. The tests revealed all VAWTs performance were better than HAWTs. GPT-2 output power is about 200-250% higher than HAWT-2. These two prototypes are equivalent in terms of the swept area. The difference is about 104% when GPT-1

and HAWT-1 are compared, although the swept area of GPT-1 is about 44% smaller than HAWT-1. It can also be observed that higher wind speed leads to a bigger gap between GPTs and HAWTs.

C_p converges on higher wind speeds. In lower wind speed, GPT with more levels outperforms the fewer number of levels, which was expected. There is also an irregular jump in GPT-1 for low wind speeds, which could be explained by the different cut-off speed of the system when there is only one level of GPT. The difference between GPT-2 and HAWT-2 in terms of C_P when wind speed is about 30 mph, is about 250%, where GPT-2 has a better performance.

The test data also indicates the in low wind speeds GPT-1 can have a better performance compared to the horizontal propeller of GPT, although in higher wind speeds it shows a negative impact.

It seems that VAWTs with small length blades have better performance and efficiency than HAWTs, which maybe be a reason HAWTs need large size and get larger and larger.

Large HAWTs may have more efficiency than VAWTs. Large HAWTs are more attractive in the application of wind farms in which large open area is available. Further study will be necessary to help with this evaluation.

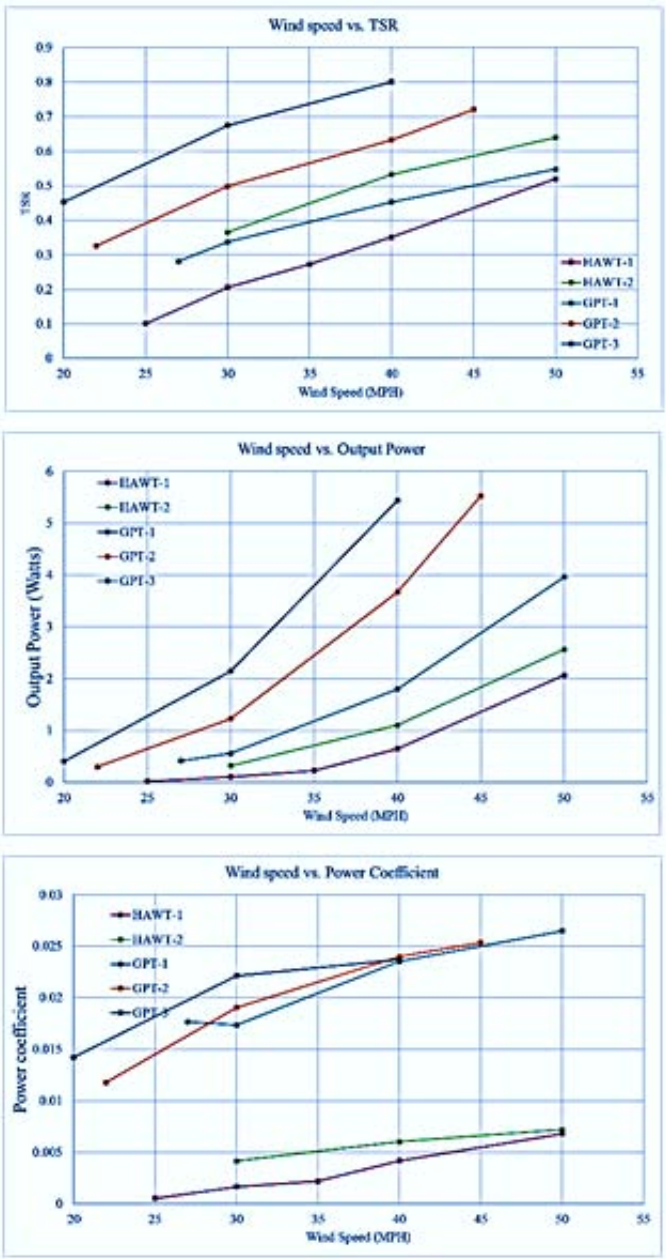

Fig. 10: Test Results and Comparison

VI. Potential Application of GPT

The GPT has all advantages and characteristics of the VAWT. Also, the GPT doesn't have exposed rotating parts. All rotating parts are covered in enclosures. Therefore, the GPT is much safer than other VAWTs. The GPT can have many applications, for instance, on buildings, towers, and bridges, including wind farms. Some of the application is illustrated in Figure 11.

Fig. 11: Potential Applications of Green Power Tower (GPT)

VII. Summary

Comparing to HAVTs, VAWTs have advantages of without long length blades and giant towers and no needing large open areas so that VAWTs can be applied in the areas, such as metropolitan, community, and resident. In the areas, VAWTs not only can efficiently utilize the wind energy but also may have cosmetic effects for the buildings and surroundings.

Most of VAWTs have unique characteristics: replaceable and stackable. The replaceable character allows an existing VAWT to be altered to another type amazingly and the stackable character lets the VAWT be upgraded conveniently to meet the load requirements. The GPT, a novel VAWT design, has no exposed rotating components which are completely covered in enclosures. The GPT prototypes were tested and the performance was significant, which showed the GPT could extract more wind energy comparing to the similar size HAWTs. The novel VAWT can have many potential applications, such as on buildings, towers, and bridges, including wind farms.

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Robust Multi-Objective Singular Optimal Control Ofpenicillin Fermentation Process

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Abstract- The determination of optimal feeding profile of fed-batch fermentation requires the solution of a singular optimal control problem. The complexity in obtaining the solution to this singular problem is due to the nonlinear dynamics of the system model, the presence of control variables in linear form and the existence of constraints in both the state and control variables. Traditionally, during the optimization process, uncertainties associated with design variables, control parameters and mathematical model are not considered. In this contribution, a systematic methodology to evaluate uncertainties during the resolution of a singular optimal control problem is proposed. This approach consists of the Multi-objective Optimization Differential Evolution algorithm associated with Effective Mean Concept. The proposed methodology is applied to determine the feed substrate concentration in fed-batch penicillin fermentation process. The robust multi- objective singular optimal control problem consists of maximizing the productivity and minimizing the operation total time.

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Gustavo B. Libotte [α], Fran S. Lobato [σ], Gustavo M. Platt [ρ] & Francisco D. Moura Neto [ω]

Abstract- The determination of optimal feeding profile of fed-batch fermentation requires the solution of a singular optimal control problem. The complexity in obtaining the solution to this singular problem is due to the nonlinear dynamics of the system model, the presence of control variables in linear form and the existence of constraints in both the state and control variables. Traditionally, during the optimization process, uncertainties associated with design variables, control parameters and mathematical model are not considered. In this contribution, a systematic methodology to evaluate uncertainties during the resolution of a singular optimal control problem is proposed. This approach consists of the Multi-objective Optimization Differential Evolution algorithm associated with Effective Mean Concept. The proposed methodology is applied to determine the feed substrate concentration in fed-batch penicillin fermentation process. The robust multi- objective singular optimal control problem consists of maximizing the productivity and minimizing the operation total time. The overall profit is considered as a post-processing criterion in the choice and implementation of a result contained in the Pareto set. The results obtained indicate that the proposed methodology represents an interesting approach to solve this kind of problem.

I. Introduction

A Singular Optimal Control Problem (SOCP) consists in determining the control variable profiles that minimize an objective function, subject to algebraic and differential constraints. In the last decade, a significant increase of control techniques in the industrial context was observed. The reason for this is mainly due to the high popularity of dynamic simulation tools and the existence of a competitive global market, in which environmental constraints and demanding market specifications require a continuous improvement of process operation. Dynamic optimization enables an automatic decision-making procedure. Therefore, as it gets established as an useful and trustworthy technology, other industrial applications are driven forward even more efficiently, such as: the addressing of hard constrained problems, the synthesis of chemical reactors networks, the uncertainties description in multiple period problems and the development of tools such as automatic differentiation (Biegler et al., 2002).

In order to solve this kind of problem, several numerical methods have been proposed (Bryson and Ho, 1975). They are usually classified according to three broad categories, regarding their underlying formulation: direct optimization methods, Pontryagin's Minimum Principle (PMP) based methods, and HJB-based methods. The PMP approach is based on the optimal control theory and requires the numerical solution of multipoint boundary value problems involving state and adjoint (costate) variables. The main difficulty associated with using this type of method is the initial estimate for the costate variables (Costa, 1996; Biegler et al., 2002).

In the context of chemical engineering, a typical example of a SOCP is the fermentation process, where the substrate concentration can be maintained at a fairly low level and unfavorable effects of a high concentration, such as growth inhibition, can be avoided. This phenomenon leads to unimodal reaction rate expressions, which exhibit a maximum point with respect to a single reactant concentration or in terms of two or more reactant concentrations. Although only one single control variable, in the form of the feed rate, may appear to characterize a simple optimal control problem, considerable difficulties have been reported in the determination of the optimal feed rate policy for fed-batch processes, due to the intrinsic nonlinearity of these systems (Hong, 1986; Modak et al., 1986; Modak and Lim, 1989; Fu and Barford, 1993; Xiong and Zhang, 2003). In this problem, the usual objective considered in the optimization of a fed-batch bioreactor is to maximize the metabolite production or the yield, that is, the production per unit of substrate fed (Hong, 1986).

Traditionally, during engineering system design, the model, the vector of design variables, and the parameter vector are considered free of errors, i.e., they do not contain uncertainties. However, more realistically, small variations in the vector of design variables may cause significant modifications in the vector of objective functions (Ritto et al., 2008). As a consequence, the system to be optimized can be very sensitive to small changes in the vector of design variables, and thus, small variations in this vector can cause significant changes in the vector of objective functions (Ritto et al., 2008). In this context, it is important to determine a methodology that produces solutions less sensitive to

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small variations in the vector of design variables. Solutions with this characteristic are called robust solutions and the procedure to find these solutions is named Robust Optimization (Taguchi, 1984).

In this contribution, the Multi-objective Optimization Differential Evolution (MODE) algorithm (Lobato, 2008), associated with the Effective Mean Concept—EMC (Deb and Gupta, 2006) is applied to determine the feed substrate concentration in fed-batch penicillin fermentation process. This robust multi-objective singular optimal control problem consists of maximizing the productivity and minimizing the operation total time. In the post-processing stage of the results, the criterion adopted to choose a point on the Pareto curve is the overall profit. This work is organized as follows. Sections 2 and 3 presents the mathematical description of the SOCP and the mathematical model that describes the fed-batch penicillin fermentation process, respectively. Section 4 shows a brief review about the MODE algorithm. The EMC strategy considered to deal with uncertainties is presented in Section 5. The results obtained are presented in Section 6. Finally, the conclusions are outlined in Section 7.

II. Optimal Control Problem

The solution of an OCP consists in the determination of the control variables profiles that maximize or minimize a measure of performance. The OCP performance index is given by:

$$\min_{u(t),t_f} J = \kappa\left(z\left(t_f\right),t_f\right)+\int_{t_o}^{t_f} L\left(z,u,t\right)dt \tag{1}$$

where κ and L are the first and second terms of the performance index, respectively. The objective is subject to the implicit Differential-Algebraic Equations (DAE) system:

$$f\left(\dot{z},z,u,t\right)=0 \tag{2}$$

with initial conditions assumed consistent and given by:

$$\varphi\left(\dot{z}\left(t_o\right),z\left(t_o\right),u\left(t_o\right),t_o\right)=0$$

where $$J(.),\ L(.),\ \kappa(.)\rightarrow\mathbb{R},\ f(.),\ \varphi(.)\rightarrow\mathbb{R}^{n_x},\ z\in\mathbb{R}^{n_z} \text{ and } u\in\mathbb{R}^{n_u}. \tag{3}$$

A comparison among methods for solving the OCP had great attention around the first part of the eighties with the development of numerical methods, appropriate to a more restricted class of problems, identified mainly by the differential index (Brenan et al., 1996).

The indirect strategy for solving the OCP is based on variational principles. These conditions, from the Pontryagin's Minimum Principle (Bryson and Ho, 1975), generate a set of Euler-Lagrange equations, which are boundary value problems (BVPs), inherently formed by the DAE, regardless of whether the problem is restricted or not. Some difficulties in the OCP solution must be highlighted: (i) the existence of end-point conditions or region constraints implies in multipliers and associated complementary conditions that significantly increase the difficulty of solving the BVP by the indirect method; (ii) the existence of constraints in the state variables and the application of the slack variables method may produce DAE of higher indexes, regardless of the constraint activation status, even in problems where the number of inequality constraints is equal to the number of control variables; and (iii) the Lagrange multipliers may be very sensitive to the initial conditions. The direct approach, on the other hand, uses the control parameterization (sequential method) or the state and control parameterizations (simultaneous method), transforming the original problem into a finite dimensional optimization problem. By all means, the implementation of direct methods is simpler because it does not demand the generation of the costate equations, which, at very least, duplicates the dimension of the set of DAE in the indirect method. On the other hand, the solution of NLP (Nonlinear Programming) problems of great dimension or the attainment of the gradients of the objective function in the sequential method is not trivial (Feehery, 2001).

The solution of OCP with inequality constraints presents an additional complexity because it demands the knowledge of the sequence and the number of constraint activations and deactivations along the trajectory. When the amount of constraints is reduced, it is usually possible to determine this sequence examining the solution of the problem without constraints. However, the presence of a large number of restrictions leads to a problem of combinatorial nature (Feehery, 2001).

A particular case of great interest is the presence of a linear control variable in the Hamiltonian function. In general, no minimum optimal solution exists for such problems, unless inequality constraints in the state and/or control are specified. If the inequality constraints are linear in the control variable, it is reasonable to expect that the minimizer, if it exists, will

always demand that the control variables are located at a point on the limits of the feasible region of control (Bryson and Ho, 1975). For this purpose, consider the following system of equations:

$$\dot{z} = F(z) + g(z)u \tag{4}$$

$$z(t_o) = z_o \tag{5}$$

with control variable given by:

$$u_{\min} \le u \le u_{\max} \tag{6}$$

The Hamiltonian function (H) is defined as:

$$H = \lambda^T \left(F(z) + g(z)u\right) \tag{7}$$

For this class of control, we have:

$$u = \begin{cases} u_{\max} & \lambda^T g < 0 \\ \Im & \lambda^T g = 0 \\ u_{\min} & \lambda^T g > 0 \end{cases} \tag{8}$$

where $\Im$ is the Switching Function (Lobato, 2004).

III. Optimization of Feed-Batch Penicillin Fermentation Process

The mathematical model of the feed-batch penicillin fermentation process considered in this contribution was described and studied by San and Stephanopoulos (1989). Mathematically, this model consists of the following constraints:

$$\frac{dX}{dt} = \mu X - \frac{FX}{V} \qquad X(0) = 1 \text{ g/L} \tag{9}$$

$$\frac{dP}{dt} = \theta X - 0.01P - \frac{FP}{V} \qquad P(0) = 0 \text{ g/L} \tag{10}$$

$$\frac{dV}{dt} = F \qquad V(0) = 2.5\text{E}5 \text{ L} \tag{11}$$

$$\mu = \frac{0.11S}{S + 0.006X} \tag{12}$$

$$\theta = \frac{0.004}{1 + 0.0001/S + S/0.1} \tag{13}$$

$$0.001 \le S \le 0.5 \text{ g/L} \tag{14}$$

$$X \le 41 \text{ g/L} \tag{15}$$

where t is the time (h), X is the biomass concentration (g/L), P is the amount of existing penicillin product (g/L), S is the substrate concentration—control variable (g/L), V is the volume of biological reactor, F is the feed rate (1666.67 L/h), μ is the growth rate and θ is the specific product formation rate.

In this work, we formulate a robust multi-objective singular optimal control problem, based on the feed-batch penicillin fermentation process, which consists of maximizing the productivity and minimizing the operation total time, describe as:

$$\max \frac{P(t_f)V(t_f)}{t_f} \tag{16}$$

$$\min\ t_f \tag{17}$$

In order to choose a point that belongs to the Pareto Curve obtained, taking into account a multi-objective optimization strategy, the overall profit (*OP*) is considered. This relation is defined as (San and Stephanopoulos, 1989):

$$OP = \int_0^{t_f} \left(-\theta\, XV + 0.0103PV + 0.0744\mu X + 0.00102XV + 6913.58\right)dt \tag{18}$$

IV. Multi-Objective Optimization Differential Evolution

Aiming to solve the multi-objective optimization problem proposed, in this section is presented a brief review about the multi-objective optimization problem and the MODE strategy, respectively. When dealing with multi-objective optimization problems, the notion of ''optimality'' needs to be extended. The most common approach in the literature was proposed by Edge worth (1881) and later generalized by Pareto (1896). This notion is called Edge worth–Pareto optimality, or simply Pareto optimality, and refers to finding good trade-offs among all the objectives. This definition leads us to find a set of solutions that is called the Pareto optimal set, whose corresponding elements are called no dominated or no inferior.

Multi-objective optimization deals with optimization problems which are formulated with some or possibly all of the objective functions in conflict with each other. Such problems can be formulated as a vector of objective functions $f(\mathbf{x}) = [f_1(\mathbf{x})\ f_2(\mathbf{x})\ \ldots\ f_m(\mathbf{x})]$ subject to a vector of input parameters $\mathbf{x} = [x_1\ x_2\ \ldots\ x_n]$, where m is the number of objectives, and n is the number of parameters. According to the criterion of Pareto, multi-objective problems have a set of trade-off solutions, where a solution may be better on objective f_1 but worse on objective f_2, whilst other solutions may be worse on objective f_1 but better on objective f_2.

The literature shows a large number of multi-objective optimization techniques, although these methods have limitations when it comes to highly complex applications (Deb, 2001). Metaheuristics have established themselves as a complementary approach that can be applied even when no prior information is known about the underlying problem. The growing popularity of evolutionary algorithms in this field is mainly due to their flexibility to deal with a wide variety of multi-objective optimization problems (both numerical and combinatorial) and to their easiness of use. Also, due to their population-based nature, evolutionary algorithms can be modified such that they generate several nondominated solutions in a single run. These features have made them popular when tackling complex real world multi-objective optimization problems (Deb, 2001).

In order to solve the multi-objective optimization problem, Lobato (2004) proposed the MODE strategy. This is based on the association between the Differential Evolution (DE) algorithm (Storn and Price, 1995) with two operators: ranking ordering and crowding distance.

This algorithm has the following structure: an initial population of size N is generated at random. All dominated solutions are removed from the population through the operator Fast Non- Dominated Sorting. This operator calculates, for each population member, represented by x_i, the number of individuals that dominate x_i (generating a domination count, n_i) and the set of candidates S_i that are dominated by x_i. Afterwards, the population is sorted into non-dominated fronts F_j (sets of vectors that are non-dominated with respect to each other) as described in the following: the vectors with $n_i = 0$ constitute the first front, F_0. For every vector in the front F_j (beginning with $j = 0$), the domination count n_i of vectors of the corresponding sets S_i is reduced by one. If a domination count becomes zero, the corresponding vector is put into the next non-dominated front F_{j+1}. This procedure is repeated until each vector becomes the member of a front.

The remaining nondominated solutions are retained for recombination. In this step, three parents are selected at random. A child is generated from these three parents (this process continues until N children are generated). Starting from population P_1 of size $2N$, neighbours are generated from each one of the individuals of the population. Those generated candidates are classified according to the dominance criterion described before and only the nondominated neighbours (P_2) are put together with P_1 to form P3. The population P_3 is then classified according to the dominance criterion. If the number of individuals of the population P_3 is larger than a predefined number, the population is truncated according to the criterion defined by the Crowding Distance criterion (Deb, 2001). The crowding distance describes the density of solutions surrounding a vector. To compute the crowding distance for a set of population members the

following procedure is conducted for each objective function: the vectors are sorted according to their objective function value. The vectors with the smallest or largest value are assigned an infinite crowding distance (or an arbitrary large number for practical purposes). For all other vectors, the crowding distance is calculated according to:

$$dist_{x_i} = \sum_{j=0}^{m-1} \frac{\left(f_{j,i+1} - f_{j,i-1}\right)}{\left(\left|f_{j,\max} - f_{j,\min}\right|\right)} \tag{19}$$

Where f_j corresponds to the j-th objective function and m is equals to the number of objective functions. This process is executed until the total number of generations is reached.

V. Effective Mean Concept

Traditionally, the introduction of robustness in the multi-objective context require the consideration of new constraints and/or new objectives (relationship between the mean and the standard deviation of the vector of objective functions) and probability distribution functions for the design variables and/or objectives (Ritto et al., 2008).

As an alternative to these classical formulations, Deb and Gupta (2006) extended the Effective Mean Concept (EMC), originally proposed for mono objective problems, to the multi-objective context. In this approach, no additional constraints are inserted into the original problem. Thus, the problem is rewritten as the mean of the original objectives. In this case, the robustness measure and the solution of a robust multi-objective optimization problem are defined as (Deb and Gupta, 2006):

$$f^{eff}(x,\delta) = \frac{1}{|B_\delta(x)|} \int_{y \in B_\delta(x)} f(y)dy \tag{20}$$

Where x is the design variables vector, f is the objective function, f^{eff} is the EMC applied to this function, δ is the robustness parameter, $|B_\delta|$ is the hyper-volume of the neighborhood in relation to the design variable x. To evaluate this integral, sample points are created randomly by using the Latin Hypercube method, in the vicinities of x. In the multi-objective context, the optimization problem is given by:

$$\min \left(f_1^{eff}(x,\delta),\ f_2^{eff}(x,\delta),\ \ldots,\ f_m^{eff}(x,\delta)\right) \tag{21}$$

$$\text{subject to } \left(g_j^{eff}(x,\delta) \le 0,\ j = 1,\ldots,k; x \in \Omega \subset \mathbb{R}^n\right) \tag{22}$$

Where g is the inequality constraints vector and m is the number of objectives.

In the present paper, the EMC is used to assess the robustness in each candidate generated by using the MODE algorithm. In this case, the original objective function vector is transformed by considering Eq. (21). The user needs to input the objective functions vector, the constraints vector, the design space, MODE parameters, the perturbation δ added to the vector of design variables, and the sample size N_{sample}.

VI. Results and Discussion

In order to solve the proposed robust multi-objective singular optimal control problem, the following parameters are considered in MODE: population size (25), number of generations (200), perturbation rate (0.8), crossover rate (0.8), number of pseud-curves (10) and reduction rate (0.9). The control variable was discretized considering 5 control elements. Three cases are considered, according to the level of uncertainty: δ = 0 % (nominal solution, i.e., without uncertainty), δ = 5 % and δ = 10%. For each test case, the number of samples was equal to 50 (N_{sample}). Considering the parameters presented above, 25+25×200 objective function evaluations are necessary to solve the nominal case by using the MODE. In order to solve the robust cases by the MODE, 25+25×200×50 objective function evaluations are necessary.

Figure 1 presents the Pareto Curve obtained by using the MODE strategy. We can observe that the increase in total operation time (t_f) implies an increase in productivity. In addition, the productivity is higher for the nominal case due to higher t_f values, following the robust cases. The overall profit (OP) is favored by increase of t_f, as observed in Tab. 1.

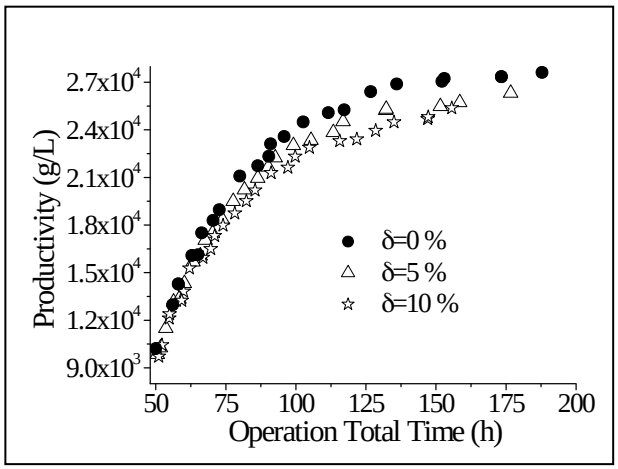

Figure 1: Pareto Curve relating the objectives, productivity and operation total time

Table 1: Some points of the Pareto Curve obtained considering $\delta = [0\ 5\ 10]$ %

δ (%)	Operation Time Total (h)	-Productivity (g/L)	-overall profit ($/g) 0
0	187.853	-27613.673	-1.066E+06
5	176.652	-26317.889	-9.660E+05
10	155.605	-25369.781	-8.444E+05

As mentioned earlier, Fig. 2 presents the evaluation of OP for each individual considering nominal and robust solutions. In this case, a good diversity, in terms of individuals of the population obtained by using MODE is observed.

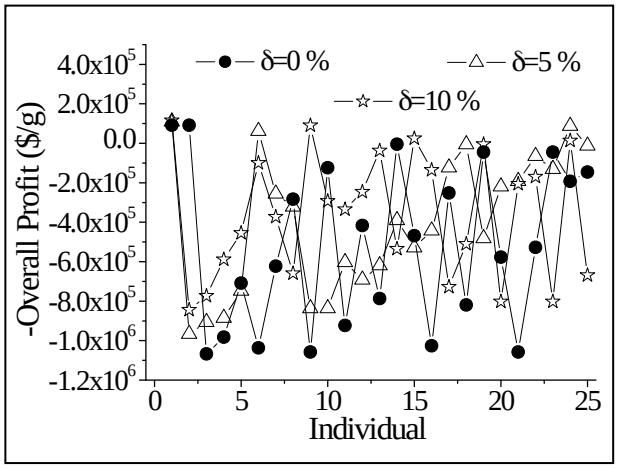

Figure 2: Overall profit versus individual

The best individuals (see Tab. 1), in terms of the *OP*, are chosen to simulate the process, as observed in Figs. 3-6. In these curves, it is important to observe that, initially, the profiles are similar, due to the proximity of the feed substrate concentration of maximum value (S=0.5 g/L) to increase the cells concentration rapidly. For each value of δ, after a determine value, the feed substrate concentration reaches a value close to the minimum (S=0 g/L) to increase the product concentration rapidly. In Fig. 6 we can observe that during the first step (S≈0.5 g/L), the process is not profitable due to the product concentration.

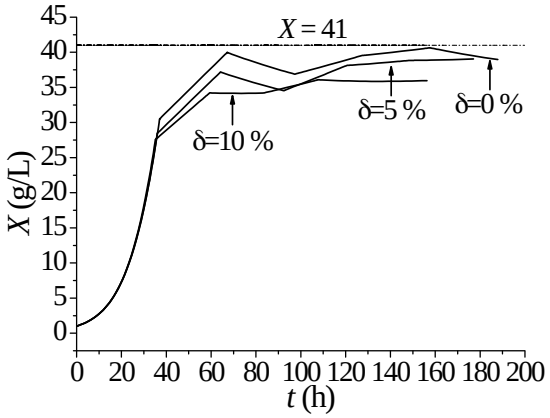

Figure 3: Cells concentration

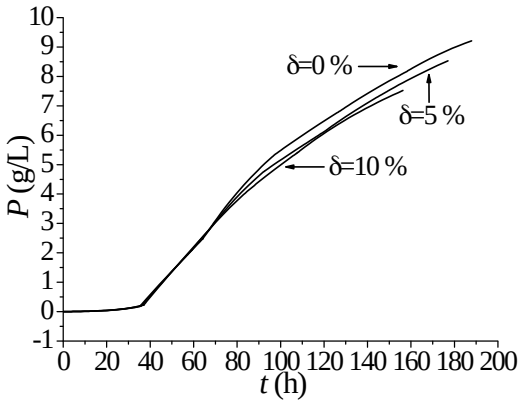

Figure 4: Product concentration

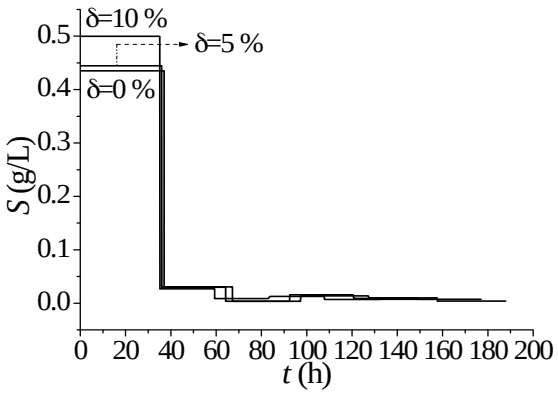

Figure 5: Substrate concentration

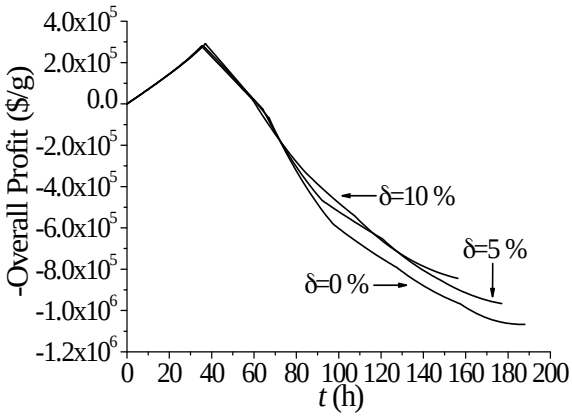

Figure 6: Overall profit

VII. Conclusion

In this paper, the MODE strategy was associated with the EMC approach to determine the feed substrate concentration in a fed-batch penicillin fermentation process. The results demonstrated that the insertion of robustness implies in the reduction of diversity of the Pareto Curve and the deterioration of the Pareto Curve in relation to nominal result.

Since a systematic study introducing robustness in multi-objective optimization problems (Deb and Gupta, 2006) is not easily available, the problem studied may serve as comparison for future evaluations of other methodologies for robust multi-objective optimization. Regarding optimal robust design, the determination of robustness regions may represent a criterion for the choice of a specific point of the Pareto Curve for a possible practical implementation. However, it is important to observe that the main disadvantage of this approach is the increase of the number of objective function evaluations, which are necessary to evaluate the integral considered in the Effective Mean Concept, independently from the optimization strategy considered.

Further works will be dedicated to approaches related to dynamically updating the parameters and mutation strategies of the MODE together with its parallelization to reduce the computational time.

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Anti-Pinch Protection Approaches on Smart Tailgate

By Satish Ullatil

Abstract- An improved system for detecting the presence of an object in the path of a liftgate relies upon the sensor and transmitters those used for collision avoidance systems to detect the presence of an object when the tailgate is closed in auto-mode. The sensors are actuated when the liftgate is moved to its closed position. When an object is detected, further movement of the liftgate stops rearward accordingly. Now a day, the capacitive sensors are widely used for the anti-pinch system considering the production cost and adaptability. Pedestrians are in at risk of meeting with fatal accidents or tailgate get mal-function due to the presence of the hard object. Car manufacturers have initiated to support by offering collision avoidance systems that detect pedestrians and objects on the powered tailgate.

Keywords: *tactile sensor, capacitive sensor, sensor profile, ultrasonic sensor, anti-pinch tail-gate, powered tailgate, application and function of capacitive sensor.*

GJRE-J Classification: *FOR Code: 090299*

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Keywords: tactile sensor, capacitive sensor, sensor profile, ultrasonic sensor, anti-pinch tail-gate, powered tailgate, application and function of capacitive sensor.

I. Introduction

Pedestrians, occupants are particularly at risk of meeting with fatal accidents or mal-function of the tailgate system while closing on auto mode. In most of the accidents, the pedestrian intrude with the tailgate un-intentionally while the tailgate closes in auto mode. The requirement of anti-pinch protection sensor detection is essential in high advanced vehicles as with the aid of sensor, it senses the human or object interface while closing. It has an obvious extension to automotive applications due to the potential for improving safety systems. Product OEM's have developed different electronic system for active smart tailgate which are safe and cost-effective solution and also fulfil the legal requirements for pedestrian protection on vehicles and predictive pedestrian protection system which can detect impending accidents or mal-functioning of the tailgate due to damage on force-full closing.

II. Objective

The objective of the paper is to provide the different approaches and methods to reduce the pedestrian fatal injuries or accidents by integrating the anti-pinch safety feature on vehicle tailgate which detect human movement or object on the tailgate in auto operating condition.

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III. Anti-Pinch Technology

It is a safety system which prevents fatal accidents and the application mal-function of powered Tailgate while operating in auto-mode.

This feature stops the tailgate's download movement when something is preventing the tailgate from closing.

There are different sensors available to implement the anti-pinch application on the powered tailgate. The types are listed below.

1. Tactile Sensor
2. Capacitive Sensor
3. Sensor Profile
4. Ultrasonic Sensor

The Anti-Pinch feature is added to one touch open powered smart tailgate of PO IES upcoming trend as part of an innovative feature addition.

a) Tactile Sensor

The tactile sensor has a character to reacts to even slight pressure, force and are sensitive to touch. The sensors are made using light optical electricity. When the tactile sensor activate, the control unit of power tailgate receives a signal and after, a very less reaction time, aims a reversal of automatic opening movement.

Tactile sensors measure the coming information in response to physical interaction with the environment. The sense of touch in human is generally modeled i.e. cutaneous sense and kinesthetic sense.

Fig. 1: Tactile sensor mounted on door seals [1]

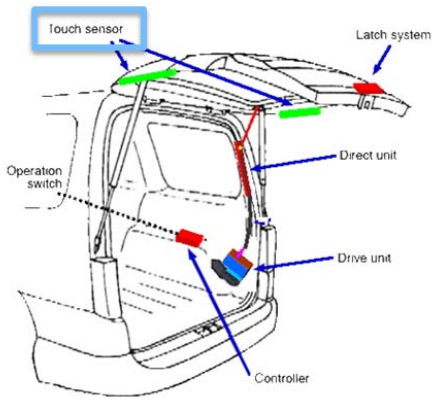


Fig. 2: Tactile sensor

b) Capacitive Sensor

Capacitive sensors tend to change the electrical field, if a person approaches the active zone of the sensor. The information is evaluate by the control unit and forwarded to the power tailgate. The non-touch detection system is a surface sensor. The sensor, which is only a few millimeters thicker is often mounted behind a plastic panel and divided into different zones (zone1 or zone2), offering sensitive responses wherever required.

Fig. 3: Zones of Sensing Regions

Fig. 4: Capacitive Senor attached on felt

Fig. 5: Capacitive Sensor Application

c) Sensor Profiles

Sensor profiles are 'pressure sensitive' sensors. The safety edges are sensors that provide anti-pinch protection at pinching and shearing edges. If the safety edge encounters an obstacle, a signal trigger that make it possible to stop immediately the movement.

The profile edge easily fit various bending radii and angles. A sensor may include an attachment member which is attached to a closure member. Sensor housing substantially encloses an associated pinching sensor where a neck portion connects the sensor housing to the attachment member and a seal extending from the neck portion and contacting a body portion of the vehicle when the closure member is in a closed position.

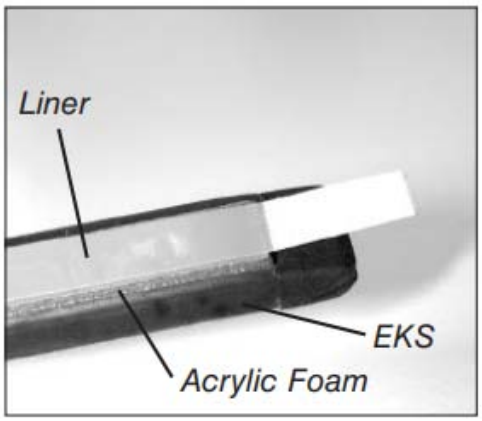


Fig. 5: Sensor Profile construction

Fig. 6: Sensor Profile position in Vehicle

Fig. 7: Sensor Profile connected to wire-harness [2]

d) Ultrasonic Sensors

Liftgate systems will include an anti-pinch algorithm system, which monitor the electrical characteristic of the motor such as current or voltage. If the electrical characteristic provides an indication that an object is in the path of the closing liftgate, then further the movement of the liftgate will be stopped, or reversed.

It is based on the ultrasonic pulse-echo method approach. The sensor senses for reflected waves on the contact with an object. The warning may be visual, audio or video.

This is adapted on powered tailgate regardless of material, form, transparency and colour. This device consists of small ultrasonic transducers that can be positioned freely and separately from electronics. They are insensitive to contamination, extraneous sound, air flows, and moisture and thus suitable for collision protection.

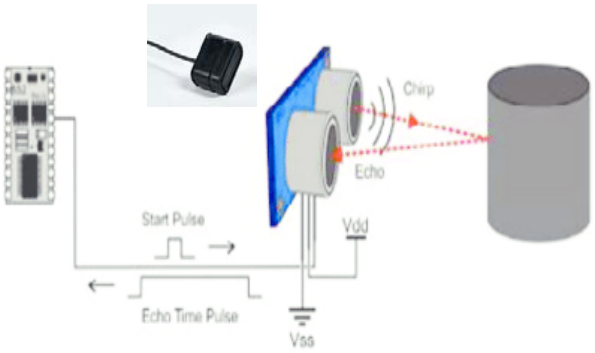


Fig. 8: Functioning of Ultrasonic sensor [3]

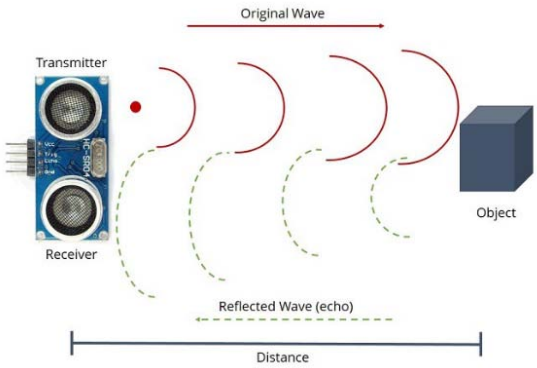
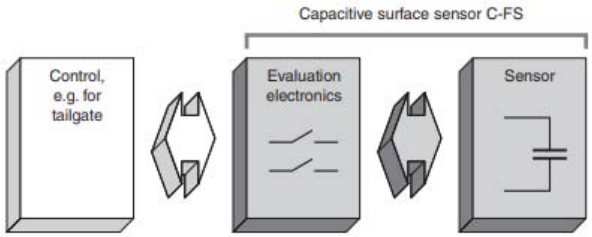


Fig. 9: Working Principle of Ultrasonic sensor

e) Working Principle of Capacitive Sensor

The capacitive sensor is used where ever powered auto tailgate must be monitored and tactile sensor are not required. This predictive technology effectively prevents collisions with persons who are in the area of the closing movement.

Principle: If a conductive object approaches the surface sensor, its capacity changes In this way, the sensor detects a person before contact is made. The connected control reverses the movement and the collusion is avoided. Since even non-conductors can hold charges, this means that just about any object can be detected with this type of sensor.



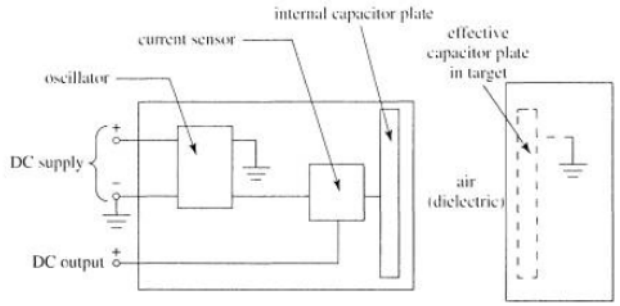
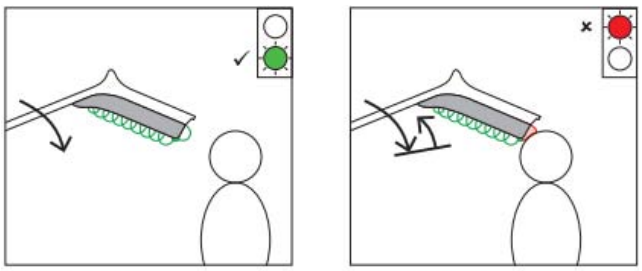


Fig. 10: Working Principle of Capacitive Sensors [3]

f) Function of Capacitive Sensor

The capacitive sensor is always surrounded by a defined capacity field. If an conductive object enters, the field changes. The sensor detects this capacitive change and causes the connected control to reverse the movement.

These types of sensor are most often used to measure the change in position of a conductive target. But capacitive sensors can be effective in measuring presence, density, thickness, and location of non-conductors as well. Non-conductive materials like plastic have a different dielectric constant than air.



Object outside
The closing movement is continued without interruption.

Object inside
Zone 2 of the sensor detects an object. The closing movement is reversed before contact is made.

Fig. 11: Functioning principle of capacitive sensor

g) Application of Capacitive Sensor

The installation is simple and reliable. The sensor is either welded on the back of a plastic applique at the defined connection points with a sonotrode or laser staked with a mandrel. The surface sensor contacts the control via the 4-pin interface type Molex Mini50TM make.

In addition to the discrete output signal, a communication signal is also available which is either of made SAE J2602 or LIN bus 2.1.

Technical Data:

Operating principle: Capacitive & Non-touch
Degree of protection: IP5K0
Standards: EN55025 & ISO 10605
Plug connection: Molex Mini 50TM

Benefits:

Reliable prevents touching & knocking over of persons
Invisible integration behind the cover
Nearly any surface geometry incl. cut-outs possible
Attachment point individually definable.
Several zone configurations are possible.

Connection point

Electronic enclosure: laser-staked on the sensor

Fig. 12: Application of capacitive sensors

IV. Advances in Technology

a) Multi-Zone Capacitive Sensor

Multi-zone Capacitive anti-pinch system is where a capacitive sensor is mounted on the tailgate and is connected to the controller which provide an output signal to the controller indicative the presence of foreign object in the path of the closure of the closure panel.

The controller varies the function of the capacitive sensor though a plurality of threshold levels as a function of the position of the closure panel as indicated by the position indicator. In a critical zone of travel with the closure panel nearing the closed position, the capacitive sensor can be utilized in either a control mode or a non-contact made or combination of both.

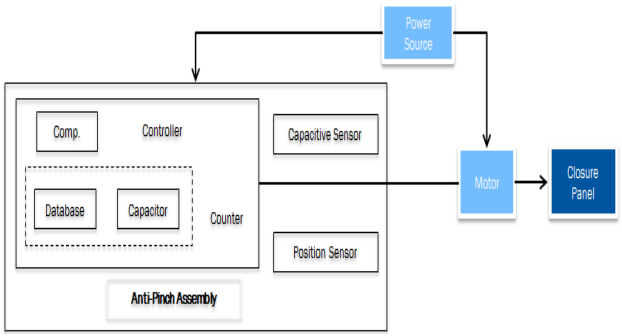


Fig. 12: Working principle of Multi-zone Capacitive Sensor [4]

b) Clipping-in Sensing Device

Provide an electrostatic capacity sensor hardly malfunctioned even in an environment splashed with water drops such as rain, or an opening and closing body clipping-in sensing device or high reliability using the same. [5] The outer surface of a sensor body and its peripheral portions are worked to get water-repellent, a detection face of the sensor main body is formed into a protruded shape, the opening and closing body is connected to a gland and the detection face of the sensor main body is arranged in a position projected to

a front door side compared with a tip of an opening and closing body end part in the opening and closing body.

c) Combined pinch/temperature sensor

A combination pinch/temperature sensor for a closure member of a motor vehicle includes a first and second pinch sensing element coupled together.

The first pinch sensing element is coupled to one of the left side and right side of the closure member for sensing a pinch condition on the corresponding side of the closure member and generating a corresponding pinch signal.

The second pinch sensing element is in electrical communication with the first pinch sensing element and is coupled to the other one of the left side and right side of the closure member for sensing a pinch condition on the other side of the closure member and generating a corresponding pinch signal. Furthermore, one of the first and second pinch sensing elements also senses an ambient temperature outside the motor vehicle and generates an ambient temperature signal for use in controlling the closure member in extreme ambient temperature conditions for powered tailgate.

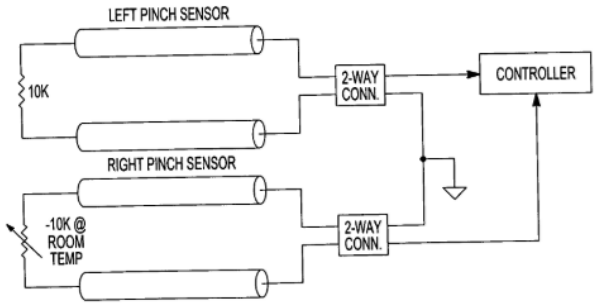


Fig. 12: Working principle of Combined Pinch Sensor

V. Conclusions

Although different collision avoidance system technologies are being developed for passenger vehicles to successfully detect pedestrians or objects in advance during vehicle tailgate closing on auto-mode to avoid fatal accidents or mal-functioning of tailgate system, the capacitive sensors are widely adapted considering the production costs, adaptability and operating cost of this technology.

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Investigation of Various Forms of Maintenance Problems Associated with Federal Housing Estate in Lagos State, Nigeria

By Akinola Victoria Olufunke & Akinola Joseph Aderemi
Federal University of Technology

Abstract- Maintenance facility in public buildings has increased rapidly among other business organizations, and thus aim to be one of leading factors in the world. Shelter has been universally accepted as the second important essential human needs after food. Housing in all ramifications is more than mere shelter as it embraces social services and utilities that make communities a livable environment. Efficient housing design is becoming imperative in urban centres; because it is an essential and fundamental component of the overall land activities in rural and urban areas. The aim of the study is to investigate various maintenance problems associated with Federal Housing Estate at AdeolaOdeku, in Lagos State. With a view to determining the effectiveness of maintenance strategies adopted and evolving good maintenance practices suitable for public estates in Nigeria. Data were obtained through reconnaissance, while surveys conducted on 6 blocks and occupiers were selected randomly.

Keywords: maintenance facility, maintenance strategy, public buildings, housing projects, shelter.

GJRE-J Classification: FOR Code: 090799

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Akinola Victoria Olufunke [α] & Akinola Joseph Aderemi [σ]

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Keywords: maintenance facility, maintenance strategy, public buildings, housing projects, shelter.

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I. Introduction

The lives of buildings are difficult to assess as all properties have, from the date of their erection, been the subject of varying amounts and standards of maintenance, besides being constructed to different standards. "Most buildings are constructed with the intention that they should last at least 60 years and many exceed this period" (Drake, 2008). Defects in the fabric of a building can result from "unrelated design decisions, unsuitable materials, incorrect assessment of loads, inadequate appreciation of conditions of use and inadequate assessment of exposure" (Cheetham, 2007).

According to James (2009), "there has been proliferation of contract forms, and much research work has taken place concerning the appropriateness of each for repair, maintenance and refurbishment work". "Maintenance units use a combination of in-house maintenance forces and private contract resources to perform their maintenance activities" (James, 2009). The appropriate maintenance outsourcing activities which should be contracted need to be determined. Some maintenance contractors may possess expertise that is not available within each unit. However, it requires additional expenses to administer maintenance outsourcing contracts, and this will need to be weighed against potential benefits.

Maintenance is a continuous operation to keep building, infrastructure, and equipment in the best form for use (Akasah *et al*., 2009). It is also to ensure the facilities are in a good condition for a life time. In achieving the sustainability of facilities condition, maintenance management required the efficiency and effectiveness for strategic planning. Building Maintenance is the work undertaken in order to keep, restore or improve every facility, i.e. every part of a building, its services and surrounds to a currently acceptable standard, and to sustain the utility and value of the building (Mills,2010). A more functional definition is that "Maintenance is synonymous with controlling the condition of a building so that its pattern lies within specified regions" (Shear, 2003).

The purpose of carrying out maintenance over property is to retain its values for investment, aesthetic, safety, durability, with a view to ensuring that the property is continually in good condition for habitation

and to the satisfaction of the owner(s)/users and communal prestige (Brennan, 2000). Housing maintenance becomes more difficult according to age of the structure and this depends on the quality of the original building coupled with the rate of maintenance of the structure (Adenuga, 1999). Maintenance of building received little attention from the users, designers and contractors (Ipingbemi, 2010).

However, most property owners sometimes keep maintenance expenditure to the least, eliminating the consequences of the long term effect of such action. On the part of the designers, they do not put into consideration durability of the materials and its serviceability before inclusion in the designs (Kunya, 2012).

The aim of this papper is to investigate maintenance problems associated with the Federal Housing Estate in AdeolaOdeku, Lagos State and strategies adopted for the maintenance of the Estate

II. Literature Review

a) Concept of Maintenance

Maintenance is primarily to preserve buildings in their initial functional, structural and aesthetic states so that they continue to remain as such and retain their investment value over a long period of existence. According to Drake (2008), it denotes all actions carried-out on a building after completion to preserve it in its initial state, starting from the defects liability period of the building to its disposal. With appropriate maintenance, the building's economic life is prolonged. However, a cursory look into some public buildings around reveals array of abandoned and epileptically functioning facilities. The malfunctioning of the facilities in most public buildings is a consequence of inadequate maintenance and/or poor management of the facilities.

BS 3811: explained that maintenance is the work or a combination of actions associated with initiation, organization and implementation carried out to retain an item in or restore it to an acceptable standard in which it can perform its required function. Hence, Kunya (2012) observed the defects in housing facilities and categorizes them as peeling of wall surface, rising dampness in substructure, floor slab failure and doors and windows defect, leaking roof while foundation failure and Sagging of beam. He further advocated that maintenance culture requires the correct diagnosis of defects, current remedial measures, sound technical knowledge of material usage, management resources as well as the formulation and implementation of integrated plan and policies to sustain utility.

Housing maintenance becomes more difficult according to age of the structure and this depends on the quality of the original building coupled with the rate of maintenance of the structure (Adenuga, 1999). It should be noted that the maintenance objective is to preserve buildings in their initial functional, structural and aesthetic states. This is to ensure that they continue to remain in such state and retain their investment value over a long period of existence (Ipingbemi, 2010). Most property owners sometimes endeavor to keep maintenance expenditure to the least, eliminating the consequences of the long term effect of such action. On the part of the designers, they may forget the durability of the materials and its serviceability before including them in their designs (Adejimi, 2005).

b) Maintenance problems associated with Housing

i. *Common defects in building*

Maintenance work is generated by ranges of factors. They include weathering, wear and tear, dirt, corrosion, structural and thermal movement, poor design, poor detailing, time, incorrect specification, damages by users, "insects, techniques and the use of new materials" (Brenan, 2000). Adenuga (2010) listed the factors below as major principal maintenance problems in buildings are:

1. Walls Problems such as Bulging walls, Cracking and spoiling concrete walls, inadequate foundation, tree rot damages, shrinkage/ swelling of clay subsoil, differential settlement, thermal movement, moisture expansion of block work, made up grounds, shrinkage of block work
2. Floor Problems such as Settlement of concrete floor, excessive deflection, sub-floor water, sulphate attack on concrete floor, screed cracking/hollow, collapse due to fungal or insect attacks, No damp proof membrane No sub flow access etc.
3. Doors/Windows Problems such as Insufficient groove, broken/cracked glass or frame, defective locks and keys, lose or twisted casements, rotten timber frames, defective putty or paint work
4. Damp Problems such as defective damp proof courses, damp basement walls, effect of leaking overflows or gutters, bridged damp proof courses, condensation on internal surfaces
5. Problem of Roofs such as Rotten battens, nails perishing, slate shipping, lack of insulating materials, sagging of timber, spread of structural roof, separation of structural elements, rot due to termite or beetle attack, perforated copper or zinc sheets, unventilated timber roof, insufficient parapet gutter, rusting of galvanized sheets
6. Wall Finishes such as flaking rendering Hollow rendering, cracking of rendering, spalling block work, Soft mortar, wrongly beaded stone work, disintegration of block work surfaces due to frost or salt action, surface deterioration of stone work.

c) Nature of Maintenance

Lee (2001) opined that nature of maintenance comprises of the following components.

i. *Repairs*

This is usually incorporated in a lease which attempts to indicate various standards such as substantial repair, good and tenantable repairs, good and substantial repairs. The word "repair" is adequate on its own and refers to the making of good, what is bad in buildings and their physical environment.

ii. *Renovation*

This consists of work done to restore a building, services and equipment by major overhaul to the original design or to improve on the original design. It could also include extensions and modifications. This could come in the form of a refurbishment which is the process of refitting an existing building to make it as good as new.

iii. *Rehabilitation*

This is an extensive work and modernization designed to upgrade a building to a modern standard, it also comes with rehabilitating the landscaped environment.

iv. *Replacement*

This inevitably occurs because of wear and tear on materials of components of a building as a result of usage. This decay or deterioration of materials and building components is usually seen in the frequent occurrence of breakdowns and offensive appearance. The frequency of replacement could often be reduced by the use of better quality materials, but the economics of this merit should be carefully studied. Replacement generally attributed to the intensity of the building components which eventually leads to the wear and tear of the building and subsequent breakdown of other facilities. Replacement as a term refers to the changing of the broken down or deteriorated building components with those component parts that are functional.

v. *Rectification*

This usually occurs in the early life of the housing. It is usually done to correct some shortcomings inherited from the initial design. It could involve the replacement of unsuitable parts of equipment or components which are faulty due to poor installation and incorrect assembly.

vi. *Servicing*

This essentially is a cleaning operation undertaken at frequent intervals. It usually deals with the prevention and ability to keep the equipment or property in a sound operating condition. It could be termed "day-to-day maintenance" as it involves day-to-day maintenance activities such as polishing, sweeping, painting of floors, doors, windows etc. It is also extended to services available within or outside the building.

d) Maintenance Strategy

Maintenance strategy is a systematic approach to upkeep the facilities and equipment and it varies from facility to facility. It involves identification, researching and execution of many repairs, replace and inspect decisions and is concerned with formulating the best life plan for each unit of the building, in coordination with production and other functions concerned (Crepo and Gupta 2005). It describes what events (e.g. failure, passing of time, condition) trigger what type of maintenance action (inspection, repair or replacement). Thus, selecting the best sustainable maintenance strategy depends on several factors such as the goals of maintenance, the nature of the facility or the equipment to be maintained, work flow patterns (process focus, product focus) and the work environment (Adejimi, 2005; and Campbell, 2006).

Maintenance strategy consists of mix of maintenance policies and maintenance techniques which vary from facility to facility (Shear, 2006).

Basically there are various classifications of maintenance strategies as identified by different authors: Corrective Maintenance (CM), Preventive Maintenance (PM) and Predictive Maintenance (PM). Swanson (2001) in his study differentiates corrective maintenance (CM), planned maintenance (PM). Ipingbemi, (2010) consider each maintenance strategy as a separate strategy. Therefore, maintenance strategies are the methods of transforming business objectives into maintenance objectives. A maintenance plan can be developed by identifying the current potential gaps in maintenance performance (Crepo and Gupta, 2005).

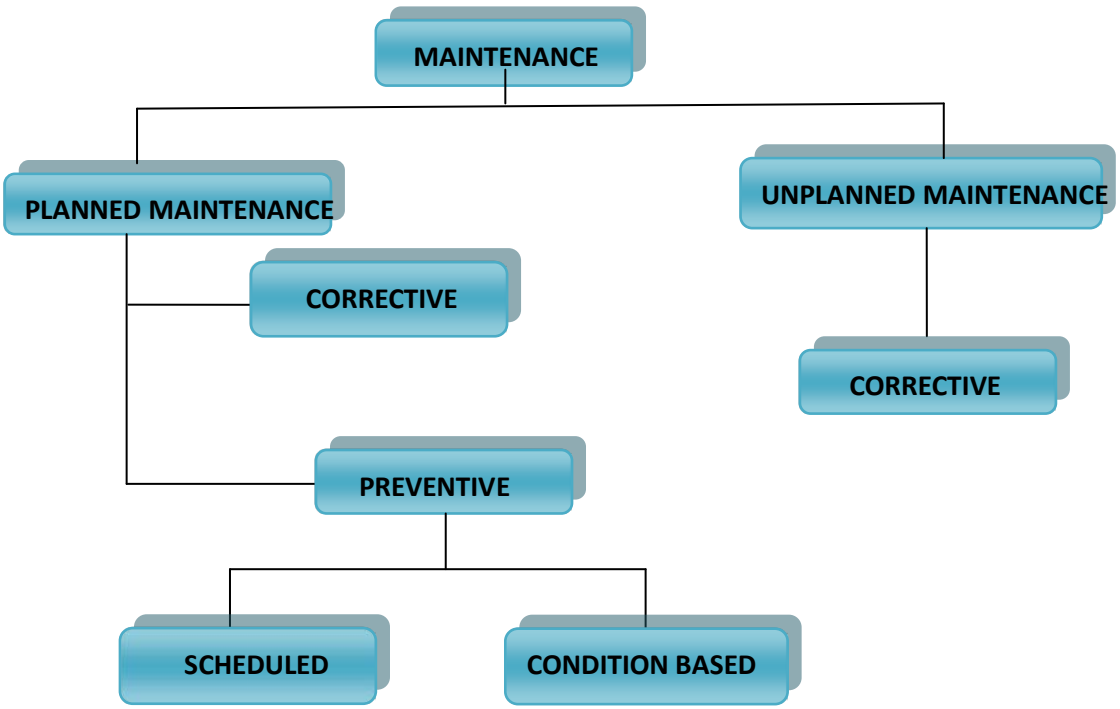

Figure 2.1: Classification of maintenance

Preventive maintenance has been described as "regular periodic work that may be necessary to retain the performance characteristics of a product as well as that required to replace or repair the product after it has achieved a useful life span" (Lee - Reginald, 2001). On the other hand, avoidable maintenance is work required to rectify failure caused by incorrect design, incorrect specification, insulation or the use of faulty materials.

e) Maintenance Strategy Formulation

The maintenance strategy requires to be supported by tactical plans. These tactical plans must be the executable plans (Campbell and Reyes-Picknell, 2006). Further, maintenance strategy needs to be reviewed periodically due to the changing environment and business requirements (Adejimi, 2005).

Therefore, the key points in formulation of maintenance strategy were identified by Drake, 2008 below:

1. Holistic approach is required to formulate maintenance strategy;
2. Structured development of maintenance strategy is must in almost every case; and
3. Apart from the structure maintenance strategy, flexible strategy is important so that it allows feedback, improvement and adjusts to changes in requirement of maintenance.

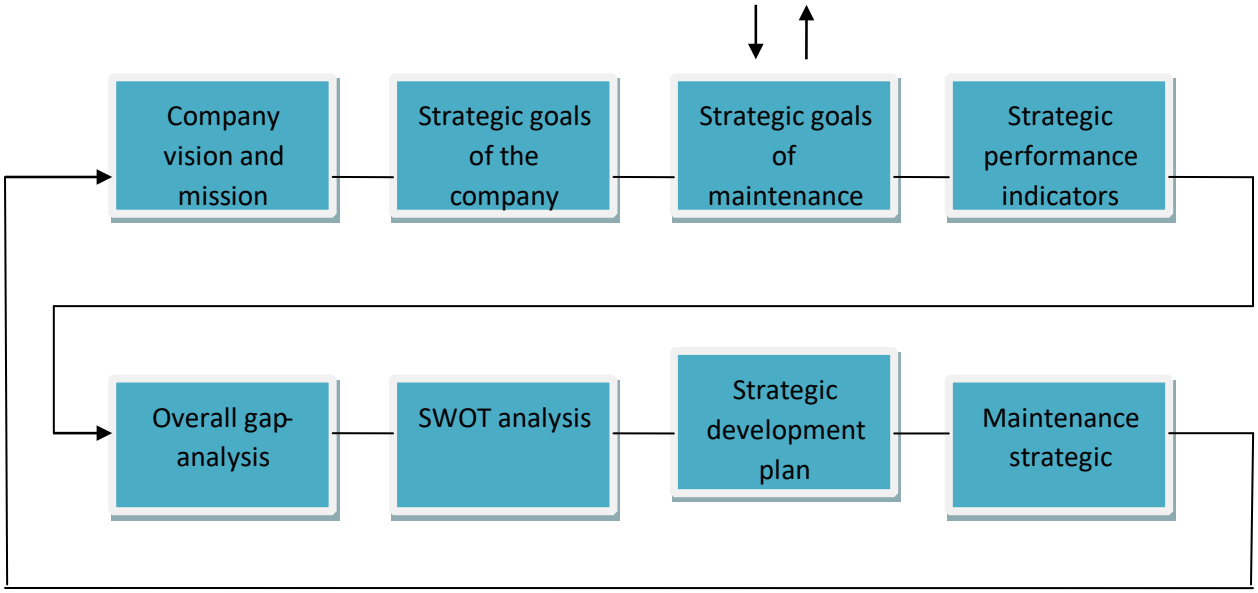

Figure 2.4: A schematic view of the work process when formulating a maintenance strategy

III. Research Methodology

The study adopted the use of both descriptive and inferential statistical tools, the descriptive statistics include the use of tables, pie chart, frequency, cumulative and percentage while inferential statistics entails mean scores, relative importance index and standard deviation. The research population comprises he occupants in the housing estate. The paper adopted questionnaire survey on 15 occupants per block using five-point Likert's scale which is based on rating. A total of ninety (90) questionnaires were retrieved and analyzed. This represents a response rate of 100% which is above 20-30% recommended for questionnaire survey in Construction Management studies by Fellow and Liu (2008) using Statistical Package for Social Science (SPSS) version 17.

IV. Data Presentation and Analysis

Table 4.1: Background of Respondents

Category	Classification	Mid-Value	Frequency	F(x)
Years of occupants by Tenants	Below 2years	0	12	0
	2-4	3	23	69
	4-6	5.0	30	150
	6-8	7.0	15	105
	Above 8years	9.0	20	180
	Total	24		504
		Mean=21		
Classification of occupation	Category	Frequency	Percentage	Cumulative
	Civil Servant	36	40	40
	Trader	12	13.3	53.3

	Self Employed	26	28.9	82.2
	Others	16	17.8	100
	Total	90	100	
Sex Distribution	Male	48	53.3	53.3
	Female	42	46.7	100
	Total	90	100	

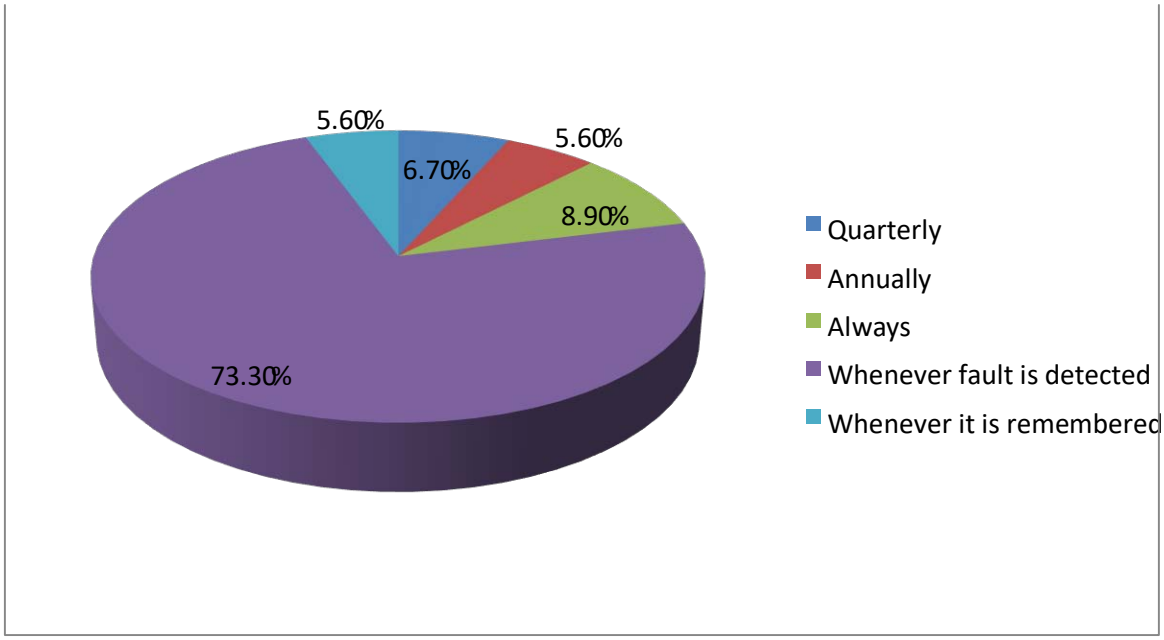

Figure 4.1: Maintenance Operation

Figure 4.1 shows that 6.7% of the respondents agreed that maintenance should be carried out quarterly, 5.6% agreed that it should be done annually, 8.9% said it is should be done always, 73.3% said it should done whenever there is fault and the remaining 5.6% said maintenance should be done whenever it is required.

Table 4.2: Various Maintenance Problems

Maintenance Problems	Mean	Std. Deviation	Ranking
leakages in pipes	3.22	.541	1
Faulty plumbing	3.14	.567	2
Elevator mechanical problems	3.00	.493	3
windows/doors	2.10	.854	4
effect of leaking overflows	2.06	.536	5
settlement of concrete floor	2.03	.636	6
bulging walls	1.92	.350	7

Damaged hose reel	1.55	.747	8
sub floor water	1.53	.585	9
swelling of walls	1.51	.792	10
cracking and spoiling concrete walls	1.51	.495	10
roof	1.40	.545	11
defective damp proof courses	1.39	.512	12
shrinkage of block work	1.39	.664	12
differential settlement	1.39	.593	12
fire hose	1.22	.572	13
Fire detectors and alarm	1.11	.782	14
Maintenance problems	**Mean**	**Std. Deviation**	**Ranking**
mechanical problems with a.c	1.09	.618	16
electrical fittings	1.02	.612	17

Table 4.2 shows various maintenance problems associated with the Federal housing estate AdeolaOdeku, Lagos state. The various maintenance problems were outlined and data were gotten from the respondents on the various major maintenance problems in the estate. The results showed that leakages of pipes were rated first with mean value of 3.72, followed by faulty plumbing (3.64), elevator mechanical problems 3rd (3.40), windows/doors 4th (2.30), effect of leaking overflow 5th (2.07), settlement of concrete floor 6th (2.00) and bulging walls 7th (1.97) while electrical fittings, mechanical problems with A.C. and poor coordination of ventilation points were the least three problems with mean value of (1.39, 1.42 and 1.48).

Thus carrying out regular maintenance works on housing estate is essential as it will improve the strength of the building and the lives of occupant will not be at risk.

a) Strategies Adopted for Solving Maintenance Problems

Table 4.3: Strategy for solving Maintenance Problems

S/N	VARIABLES	CORRECTIVE MAINTENANCE	%	PLANNED PREVENTIVE MAINTENANCE	%	PREDICTIVE MAINTENANCE	%
1	SELDOMLY	1 2	13.33	14	15.56	43	47.78
2	OFTEN	17	18.89	31	34.44	31	34.44
3	VERY OFTEN	61	67.78	45	50	16	17.78
	TOTAL	90	100	90	100	90	100

Table 4.3, shows the strategy analysis for solving problems of maintenance, for corrective maintenance, 13.33 % respondents agreed to use corrective maintenance seldomly, while 18.89% agreed for often, 67.78% agreed that it should be used very often. Therefore, Corrective maintenance is used for the maintenance of the estate.

15.56% of the respondents agreed seldomly, 34.44% of of the respondents agreed to often while 50% of used very often. Therefore, planned preventive is one of the strategies used in maintaining the estate.

47.78% of the respondents agreed that predictive maintenance is used seldomly, 34.44% of the respondents agreed to very often while 17.78% of the respondents agreed to very often.

V. Conclusion

Buildings deteriorate due to ageing, usage and adverse weather condition. For buildings to be habitable, and withstand the test of time, it requires constant and proper maintenance. Maintenance culture is necessary to keep the building in a good state. The

journey to effective and efficient strategy for maintenance of building project, for this research work depends on the reputation and resources. This research has given insight into information on the problems of maintenance in the estate and the appropriate maintenance strategy executed on the maintenance work in the estate. The critical survey carried out on the Federal housing estate AdeolaOdeku, Lagos in this work had resulted into giving useful and relevant information about public housing maintenance in Lagos State and Nigeria as a whole.

Practical suggestions towards solving the problems unravelled have proffered for implementation by the various sectors concerned. As a matter of fact the government is advised to include maintenance inside the budget and make it realistic so as to add value to However, success in this direction requires dedication, commitment and deep sense of conviction on the part of those involved in the maintenance process.

The study recommended that the choice of execution of building maintenance work should depend on the one that offers greater advantage in terms of cost, quality and convenience, also Professional bodies should organize seminars and workshops to sensitize the staff on the use of effective maintenance culture while carrying out maintenance work thus Adequate funds should be made available always to carry out maintenance work on the estate buildings.

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Acknowledgments

Contributors to the research other than authors credited should be mentioned in Acknowledgments. The source of funding for the research can be included. Suppliers of resources may be mentioned along with their addresses.

Declaration of funding sources

Global Journals is in partnership with various universities, laboratories, and other institutions worldwide in the research domain. Authors are requested to disclose their source of funding during every stage of their research, such as making analysis, performing laboratory operations, computing data, and using institutional resources, from writing an article to its submission. This will also help authors to get reimbursements by requesting an open access publication letter from Global Journals and submitting to the respective funding source.

Preparing your Manuscript

Authors can submit papers and articles in an acceptable file format: MS Word (doc, docx), LaTeX (.tex, .zip or .rar including all of your files), Adobe PDF (.pdf), rich text format (.rtf), simple text document (.txt), Open Document Text (.odt), and Apple Pages (.pages). Our professional layout editors will format the entire paper according to our official guidelines. This is one of the highlights of publishing with Global Journals—authors should not be concerned about the formatting of their paper. Global Journals accepts articles and manuscripts in every major language, be it Spanish, Chinese, Japanese, Portuguese, Russian, French, German, Dutch, Italian, Greek, or any other national language, but the title, subtitle, and abstract should be in English. This will facilitate indexing and the pre-peer review process.

The following is the official style and template developed for publication of a research paper. Authors are not required to follow this style during the submission of the paper. It is just for reference purposes.

Manuscript Style Instruction (Optional)

- Microsoft Word Document Setting Instructions.
- Font type of all text should be Swis721 Lt BT.
- Page size: 8.27" x 11'", left margin: 0.65, right margin: 0.65, bottom margin: 0.75.
- Paper title should be in one column of font size 24.
- Author name in font size of 11 in one column.
- Abstract: font size 9 with the word "Abstract" in bold italics.
- Main text: font size 10 with two justified columns.
- Two columns with equal column width of 3.38 and spacing of 0.2.
- First character must be three lines drop-capped.
- The paragraph before spacing of 1 pt and after of 0 pt.
- Line spacing of 1 pt.
- Large images must be in one column.
- The names of first main headings (Heading 1) must be in Roman font, capital letters, and font size of 10.
- The names of second main headings (Heading 2) must not include numbers and must be in italics with a font size of 10.

Structure and Format of Manuscript

The recommended size of an original research paper is under 15,000 words and review papers under 7,000 words. Research articles should be less than 10,000 words. Research papers are usually longer than review papers. Review papers are reports of significant research (typically less than 7,000 words, including tables, figures, and references)

A research paper must include:

a) A title which should be relevant to the theme of the paper.
b) A summary, known as an abstract (less than 150 words), containing the major results and conclusions.
c) Up to 10 keywords that precisely identify the paper's subject, purpose, and focus.
d) An introduction, giving fundamental background objectives.
e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition, sources of information must be given, and numerical methods must be specified by reference.
f) Results which should be presented concisely by well-designed tables and figures.
g) Suitable statistical data should also be given.
h) All data must have been gathered with attention to numerical detail in the planning stage.

Design has been recognized to be essential to experiments for a considerable time, and the editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned unrefereed.

i) Discussion should cover implications and consequences and not just recapitulate the results; conclusions should also be summarized.
j) There should be brief acknowledgments.
k) There ought to be references in the conventional format. Global Journals recommends APA format.

Authors should carefully consider the preparation of papers to ensure that they communicate effectively. Papers are much more likely to be accepted if they are carefully designed and laid out, contain few or no errors, are summarizing, and follow instructions. They will also be published with much fewer delays than those that require much technical and editorial correction.

The Editorial Board reserves the right to make literary corrections and suggestions to improve brevity.

Format Structure

It is necessary that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

All manuscripts submitted to Global Journals should include:

Title

The title page must carry an informative title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) where the work was carried out.

Author details

The full postal address of any related author(s) must be specified.

Abstract

The abstract is the foundation of the research paper. It should be clear and concise and must contain the objective of the paper and inferences drawn. It is advised to not include big mathematical equations or complicated jargon.

Many researchers searching for information online will use search engines such as Google, Yahoo or others. By optimizing your paper for search engines, you will amplify the chance of someone finding it. In turn, this will make it more likely to be viewed and cited in further works. Global Journals has compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

Keywords

A major lynchpin of research work for the writing of research papers is the keyword search, which one will employ to find both library and internet resources. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining, and indexing.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy: planning of a list of possible keywords and phrases to try.

Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, “What words would a source have to include to be truly valuable in a research paper?” Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

Numerical Methods

Numerical methods used should be transparent and, where appropriate, supported by references.

Abbreviations

Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

Formulas and equations

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

Figures

Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

Preparation of Eletronic Figures for Publication

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution at final image size ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs): >350 dpi; figures containing both halftone and line images: >650 dpi.

Color charges: Authors are advised to pay the full cost for the reproduction of their color artwork. Hence, please note that if there is color artwork in your manuscript when it is accepted for publication, we would require you to complete and return a Color Work Agreement form before your paper can be published. Also, you can email your editor to remove the color fee after acceptance of the paper.

Tips for Writing a Good Quality Engineering Research Paper

Techniques for writing a good quality engineering research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

4. Use of computer is recommended: As you are doing research in the field of research engineering then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.

22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.

23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.

- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- Single section and succinct.
- An outline of the job done is always written in past tense.
- Concentrate on shortening results—limit background information to a verdict or two.
- Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- Explain the value (significance) of the study.
- Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

The Administration Rules

Administration Rules to Be Strictly Followed before Submitting Your Research Paper to Global Journals Inc.

Please read the following rules and regulations carefully before submitting your research paper to Global Journals Inc. to avoid rejection.

Segment draft and final research paper: You have to strictly follow the template of a research paper, failing which your paper may get rejected. You are expected to write each part of the paper wholly on your own. The peer reviewers need to identify your own perspective of the concepts in your own terms. Please do not extract straight from any other source, and do not rephrase someone else's analysis. Do not allow anyone else to proofread your manuscript.

Written material: You may discuss this with your guides and key sources. Do not copy anyone else's paper, even if this is only imitation, otherwise it will be rejected on the grounds of plagiarism, which is illegal. Various methods to avoid plagiarism are strictly applied by us to every paper, and, if found guilty, you may be blacklisted, which could affect your career adversely. To guard yourself and others from possible illegal use, please do not permit anyone to use or even read your paper and file.

Criterion for Grading a Research Paper (Compilation) by Global Journals

Please note that following table is only a Grading of "Paper Compilation" and not on "Performed/Stated Research" whose grading solely depends on Individual Assigned Peer Reviewer and Editorial Board Member. These can be available only on request and after decision of Paper. This report will be the property of Global Journals.

Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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