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Study of the Variation of Lamp Electrode Temperature for Low Power Factor Self Ballasted Compact Fluorescent Lamp(S)

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Abstract

This paper attempts to study the variation of the electrode parameters particularly the temperature before the glow to arc transition occurs (T_h) and the ratio of the hot resistance (R_h) to the cold resistance (R_c) of the lamp electrodes. The variations are observed with different operating cycles of self ballasted compact fluorescent lamps. The ratio of the hot resistance to cold resistance is closely related to the electrode temperature for the self ballasted fluorescent lamps. The wide variation of the electrode temperature with different operating cycles and their corresponding R_h/R_c ratio is an indication of the switching cycle the lamp is able to withstand. It is thereby justified that the temperatures at which the lamp fails to endure is responsible for the lamp failure. This increase in electrode temperature is attributed to the low power factor of the lamps. For the sake of study four samples each of same wattage of self ballasted fluorescent lamps from different manufacturers were selected. The lamps were then subjected to a 5minutes-ON and 5 minutes- OFF switching cycles. The different values off electrode temperature were evaluated and compared with the R_h/R_c along the course of the lamp lifetime.

Keywords-lamp electrodes, hot resistance and cold resistance, compact fluorescent lamp, operating cycles.

I. Introduction

The lifetime prediction of self ballasted compact fluorescent lamps depends on several factors of which the ratio of hot resistance (R_h) to cold resistance (R_c) of the electrode is also significant. Among the several factors which were held responsible in evaluating lamp lifetime, the electrode resistances both in hot and cold condition are very much significant in the process of lamp lifetime prediction [1]. It is a well known fact that the lamp lifetime is mainly dependent on the sputtering and evaporation of the lamp electrodes. The electrodes when subjected to continuous switching, the barium oxide coating that covers the lamp electrodes is gradually depreciated. It is this depreciation that is responsible for the loss of lamp life.

Fluorescent lamp electrodes work generally in hot spot mode that is characterized by a localized electron emission around the hottest point of the electrode. As electron emission is mainly driven by the coating temperature, the hot spot has to be maintained at a sufficient temperature to sustain the lamp current imposed by the power supply [2]. The electrode temperature is primarily governed by the current flowing in the lamp electrodes. A rise in temperature of the electrodes implies loss of emissive coating by evaporation and sputtering. The emissive material removed from the electrode surface diffuses in the discharge tube and is finally deposited on the internal surface of the lamp wall around the electrode region.

A compact fluorescent lamp electrode is mainly made of tungsten filament covered by the barium oxide (emissive paste), and as the tungsten temperature is directly related to its resistivity, a profile of the electrode temperature can be obtained by measuring the hot resistance of the lamp electrode.

II. Electrode Temperature Measurement of Lamp Electrode

The thermal inertia (the ability of a given volume of a substance to store internal energy while undergoing a given temperature change) of the lamp electrode, is dependent on the emissive material encapsulating it. At lower discharge current due to joule heating of the electrode the cathode fall voltage adjusts to increase ion energy to maintain the electrode at a definite temperature to drive the required current. This can lead to intense emissive material sputtering and most likely for an impending electrode failure.

The more the heat rate the lower the thermal inertia and higher the loss of the emissive material. The compact fluorescent lamp electrode primarily consists of tungsten and its temperature is directly related to the resistance. Hence a profile of the electrode temperature is obtained by observing its hot resistance. Thus it becomes an important aspect to access the heat rate of the lamp electrode. In order to obtain this the electrode is supplied with a constant current thereby measuring its voltage during the transient stage. When the temperature is in equilibrium the voltage is constant and steady state is achieved. Thus from the voltage and current relationship hot resistance is measured. The process is repeated for several cycles in regular intervals till the lamp is burnt out.

In the forth coming section the profile of the electrode temperature for compact fluorescent lamps is observed by selecting lamps of same wattage but from different manufacturers. Usually two sets of lamp wattage are selected for the experiment- 15W and 18W.

The duty cycle opted for this experiment is chosen as 5minutes-ON and 5 minutes-OFF [3]. It has been observed that if the lamp ‘OFF’ time is less than a minute then the electrode does not cool off completely. This reduces the potentiality of damaging the electrodes .A time interval of 5 minutes –‘OFF’ is adopted so that the electrode temperature is cooled down before the next successive starting occurs. Similarly an interval of 5 minutes-ON is chosen in order to minimize the sputtering of the lamp electrodes.

In the rapid cycle test hence adopted the ratio of hot resistance (R_h) to the cold resistance (R_c) for each compact fluorescent lamp is measured. The R_h/R_c ratio is an indicator of the electrode temperature immediately before the starting of the lamp. It has been seen that an R_h/R_c ratio of 4.25 is equivalent to an electrode temperature of 700° C, which is considered to be the optimum temperature for proper lamp starting. Hence it is important for a lamp – ballast combination to have an appropriate electrode temperature during lamp starting in order to minimize the damage to the lamp electrodes. It has been found from the findings of G. Mortimer that the electrode temperature of the lamp before the glow to arc transition occurs can be evaluated using the relation: $\boldsymbol{T_h} = (\frac{\boldsymbol{R_h}}{\boldsymbol{R_c}})^{\boldsymbol{0.814}} \times \boldsymbol{T_a}$ [4], where T_h is the electrode temperature before the glow to arc transition occurs; T_a is the ambient temperature usually considered to be 298°K; R_h is the hot resistance of the lamp at the end of the preheat period and R_c is the cold resitance of the lamp electrode measured at the room temperature (25°C$\pm$1).

In the forthcoming section the variations of T_h with changes in R_h/R_c is observed and analyzed for the set of compact fluorescent lamps under observation.

III. Experimental Procedure

The accelerated life test (as shown in the figure1) was conducted based on the IESNA 1991 standard, with a total of eight lamps, four each from 15W and 18W category. The sample size of the self ballasted compact fluorescent lamps under each testing was four lamps. The switching cycle adopted for the accelerated test is: 5 minutes ON/5 minutes OFF. The lamp switching is controlled using a series of current sensors and customized timer-counter pair (as shown in figure 2). The lamp failures were detected manually during the working hours, however in case of the failures the current sensor will not sense any lamp current and thus the time count will automatically come to a halt. Hence the failures are automatically addressed even if manual checks are not possible round the clock. During the testing the room temperature was varied between 22°C to 25°C.

In order to measure the hot resistances at the end of preheat time, it is necessary to measure the peak-to-peak lamp voltage (V_{pkpk}) during start-up. Then the rms value of the lamp voltage (V_{rms}) during start-up is measured using the relation,

$$V_{rms} = \left(\frac{V_{pkpk}}{2.8284}\right) [5].$$

Secondly, rms value of the current (I_{rms}) is measured using an external DC power supply and applying a DC at the lamp electrode equal to the measured rms value of the lamp voltage, as depicted in figure 3. Thus the hot resistance of the lamp electrode is evaluated for each interval as the ratio of V_{rms} to I_{rms}.

The measured values of R_h/R_c were then used to evaluate the hot electrode temperature (T_h) before the lamp glow to arc transition occurs. The values for the electrode temperature were evaluated based on the study of G. Mortimer using the relation: $\boldsymbol{T_h} = (\frac{\boldsymbol{R_h}}{\boldsymbol{R_c}})^{\mathbf{0.814}} \times \boldsymbol{T_a}$, where the symbols are already defined in the previous section.

Fig.1 Front view of the test rack

Fig.2. Inside of the life test rack with Timer-counter pair

The lamps under test were subjected to the switching cycle of 5 minutes –ON and 5 minutes- OFF until the lamps were burnt out and the counter thus placed displayed the entire duration the lamp on and off time i.e. t_{on+off} . The figure 4 is an example of a burnt-out lamp electrode of the lamp in operation.

Fig.3. Hot electrode resistance of the lamp in progress with the left hand display measuring the current and the right hand the voltage.

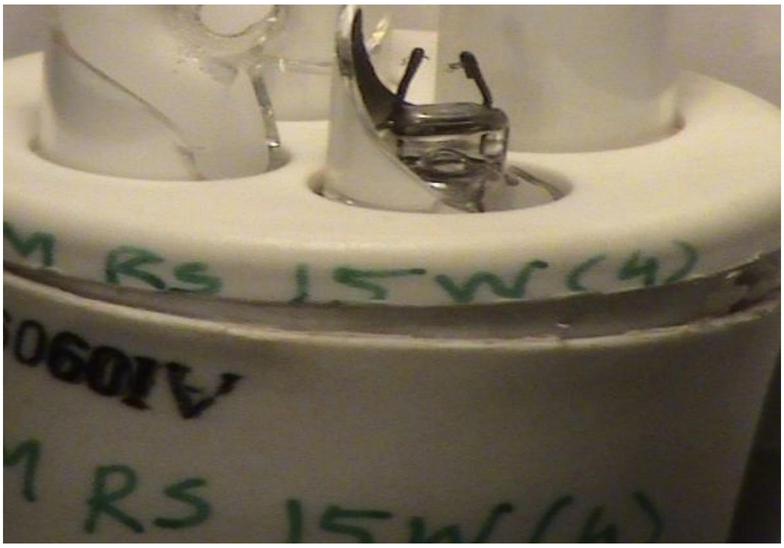

Fig.4. A burnt-out lamp electrode of 15W specified as 15C

IV. Experimental Results

The experimental result of the series of experiments hence conducted reveals certain facts about the electrode temperature during various intervals of lamp operation. The electrode temperature at various stages of lamp operation were calculated using the relation $\boldsymbol{T_h} = (\frac{R_h}{R_c})^{0.814} \times \boldsymbol{T_a}$, the variables are recognized with their usual meanings. The lamps were labeled as 18A, 18B, 18C and 18D for the 18W self ballasted compact fluorescent lamps. While the 15W self ballasted lamps were labeled as 15A, 15B, 15C and 15D. The output power factor for all those lamps was very low as compared to the IEC standards. The values for electrode temperature against R_h/R_c

were tabulated and plotted. It has been observed that generally an electrode temperature of around 700°C or 973°K is held to be the minimum temperature responsible for the glow to arc transition to occur.

For the 18W sample under test there were two lamps that eventually failed .The sample labeled as 18C and 18D failed after being able to withstand a switching cycle of 2840 and 352 respectively.

The samples under test were observed that the electrode temperature during the beginning of the lamp cycle for 18D were 921°K (648°C) before being burnt-out at 1046°K (773°C). It has been observed that the electrode temperature just before the lamp failure of 18C lamp was 1210.92°K (936.51°C). The high electrode temperature implied a greater amount of evaporation of the emissive material and thus affecting the lamp life.

For 18A, (as shown in figure 5) at the commencement of the cycle the electrode temperature was also at 773°C. The plot for electrode temperature versus number of switching cycle is shown in figure 6.However for 18B and 18C (figure 8 and 10), the electrode temperature profile are similar. The electrode temperature at the beginning of the switching cycle were at at the beginning of the lamp cycle were at 1138°K (865°C) but dropped eventually to around 1100°K before rising again. The results obtained from different lamps for 18W were tabulated as shown along with the respective plots for T_h versus R_h/R_c and T_h with the operating cycle. The plot for the electrode temperature and the operating cycles the pattern of temperature rise of the stressed electrodes were observed.

The results for 15W were similarly evaluated and plotted as shown in the figure11 to figure16 both for the electrode temperature and R_h/R_c and the electrode temperature profile along with the various switching cycles sustained. For the 15W variety there were three lamp failures, the samples designated as 15C and 15D failed after sustaining 710 and 610 number of switching cycles respectively.

In the case of 15A as shown in figure11-12, the starting temperature were as high as around 1300°K before following a similar electrode temperature profile as depicted for the 18W in the figure 8 and figure 10.

For the 15W lamp, designated as 15C (see figure15-16), the electrode temperature were 1269.34°K (996.34°C) and dropped to 1260.34°K(987.34°C) before being burnt-out. Similarly for the 15D lamp the electrode temperature at the beginning of the switching cycle was 1298.60°K before being burnt-out at 1367.50°K after withstanding 610 switching cycle.

The 15W lamps (designated in figure 11 to figure 14), the electrode temperature at the beginning of the operating cycle was reasonably high at 1337°K and 1321.08°K respectively. The high electrode temperatures at the starting are a significant observation for the low wattage lamps.

This phenomenon was observed for almost all the lamps that exhibited a very high electrode temperature during starting. At the same time the lamps with a very high electrode temperature were unable to withstand a very long duration of switching cycle. It may be generalized that the electrode temperature profile for the self ballasted compact fluorescent lamps are similar as shown in figure8, figure10 and figure12. It was evident from the series of experiments conducted that the lamps with a very low output power factor showed signs of a very high electrode temperature and R_h/R_c ratio during lamp starting and during the course of lamp operation thus eventually burning-out the lamps. The lamps with a starting electrode temperature over 0°K dropped down before rising again.

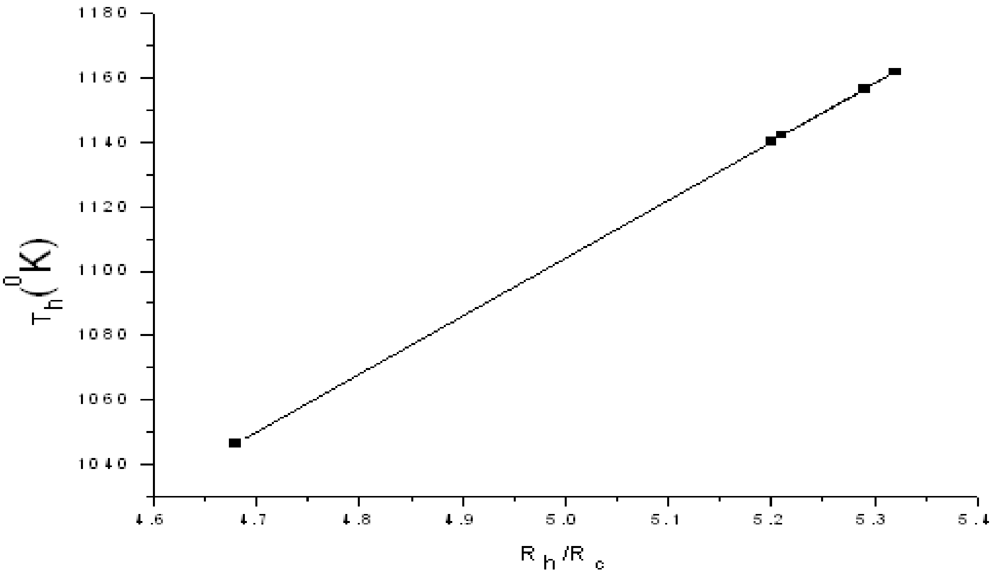

Fig 5. Plot of Th(°K) versus Rh/Rc for the 18A CFL

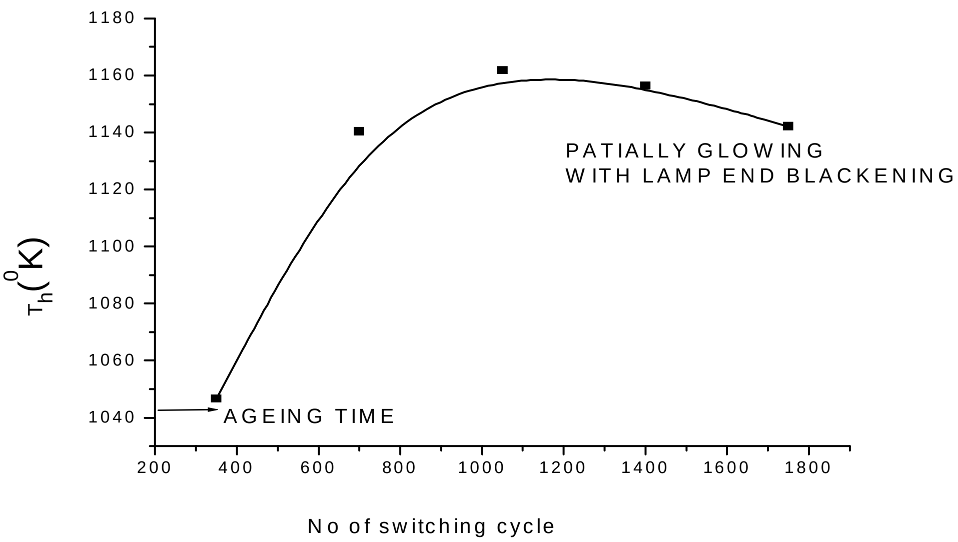

Fig.6. Plot of Th(°K) versus switching cycle for the 18A CFL.

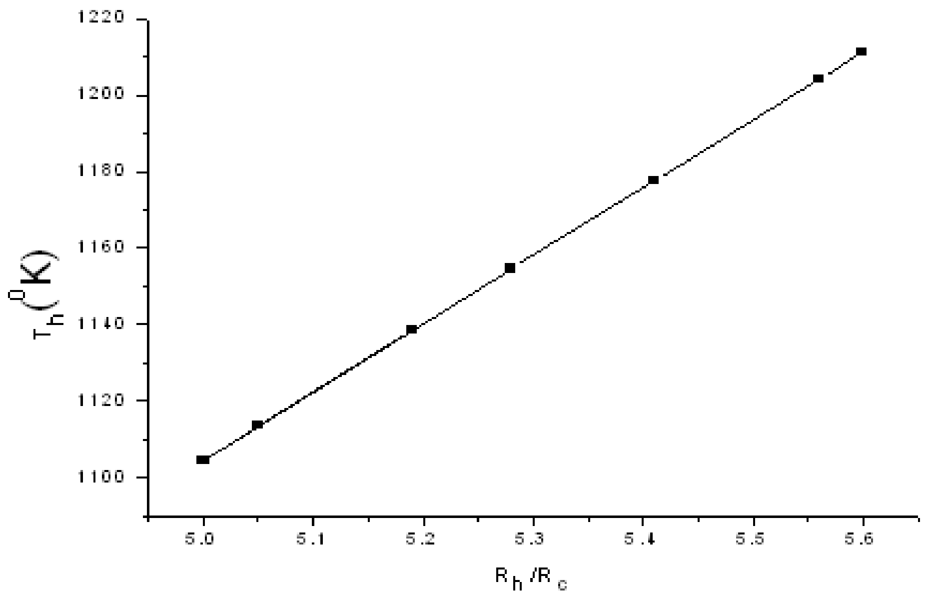

Fig. 7. Plot of Th(°K) versus Rh/Rc for the 18B CFL.

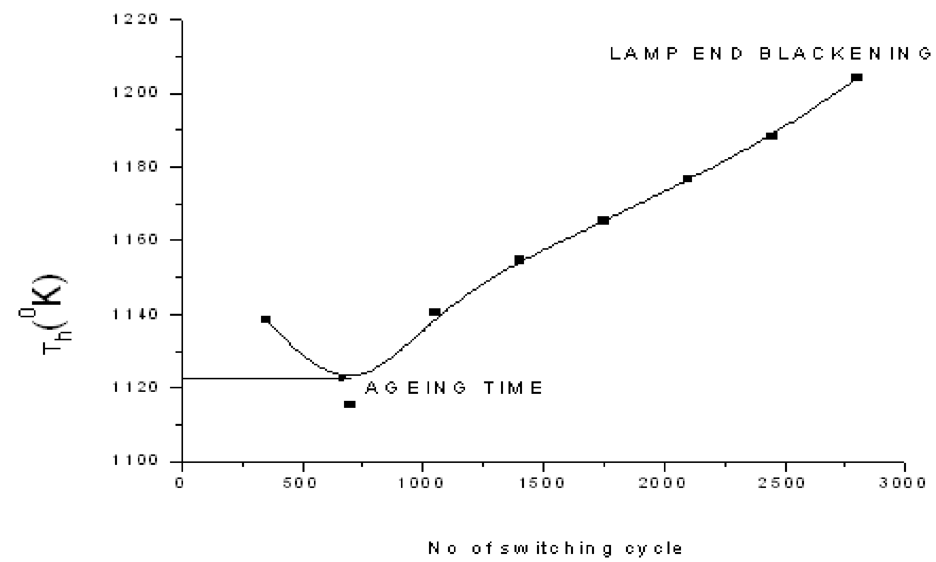

Fig. 8. Plot of T_h (°K) versus switching cycle for 18B CFL.

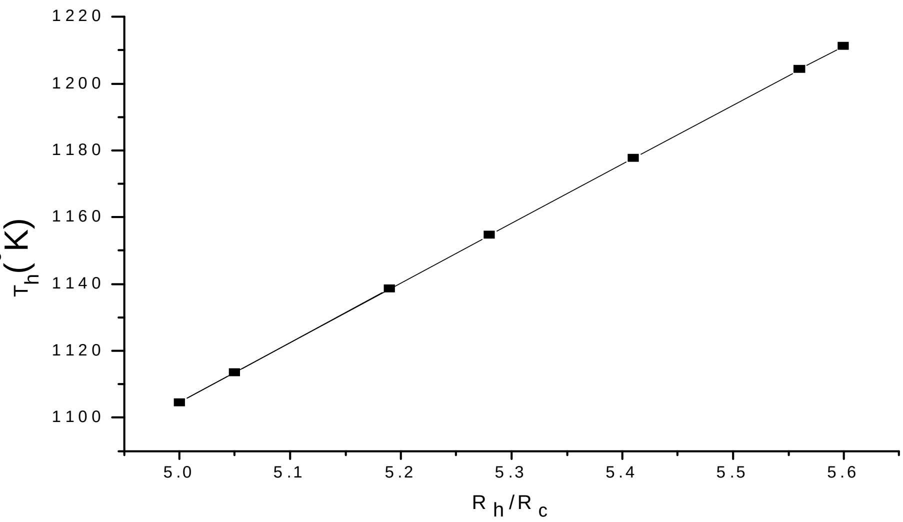

Fig. 9. Plot of Th (°K) versus Rh/Rc for the 18C CFL

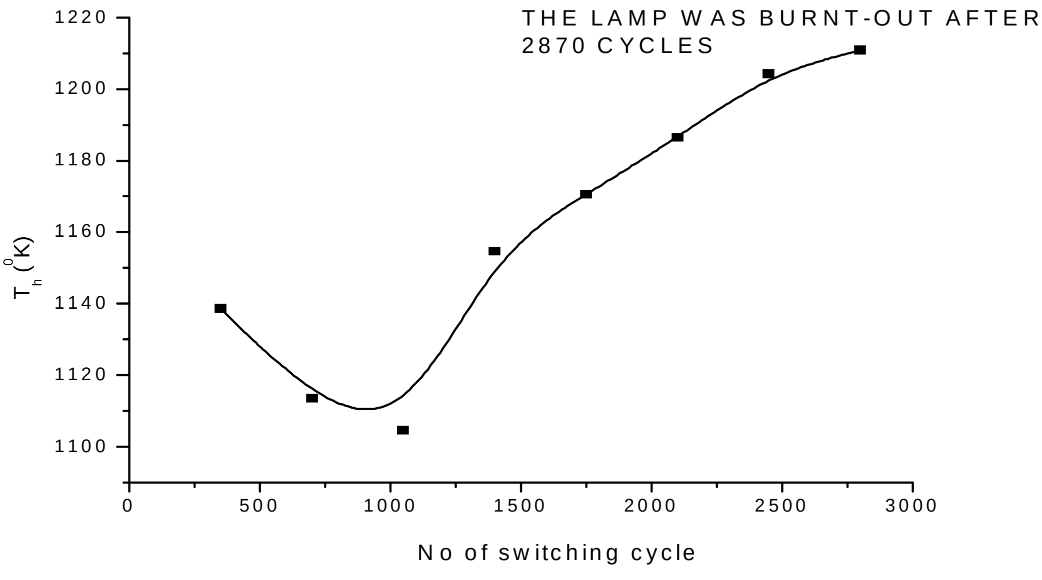

Fig. 10. Plot of Th (K) versus switching cycle for 18C CFL.

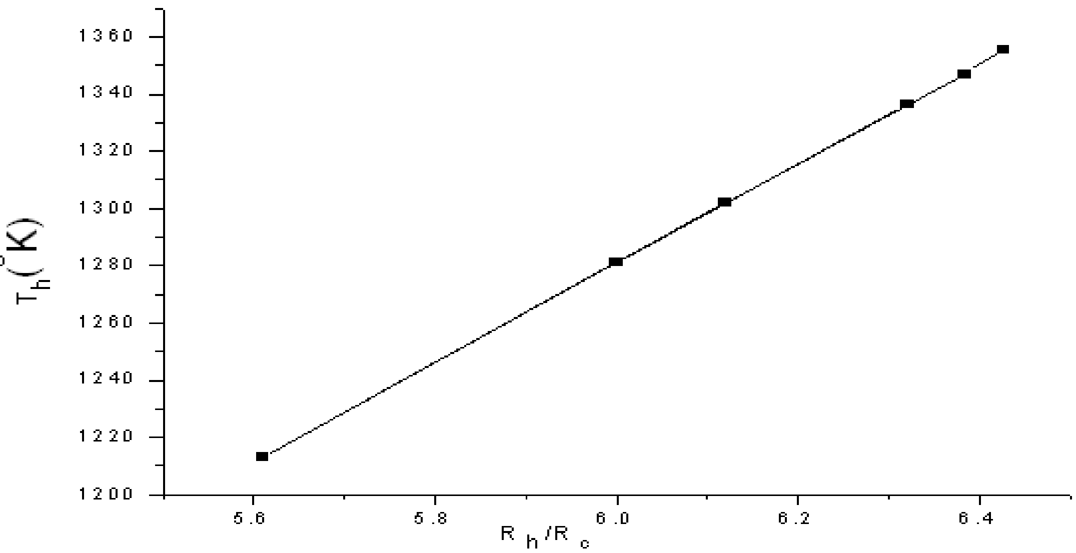

Fig. 11. Plot of T_h (°K) versus R_h/R_c for the 15A CFL.

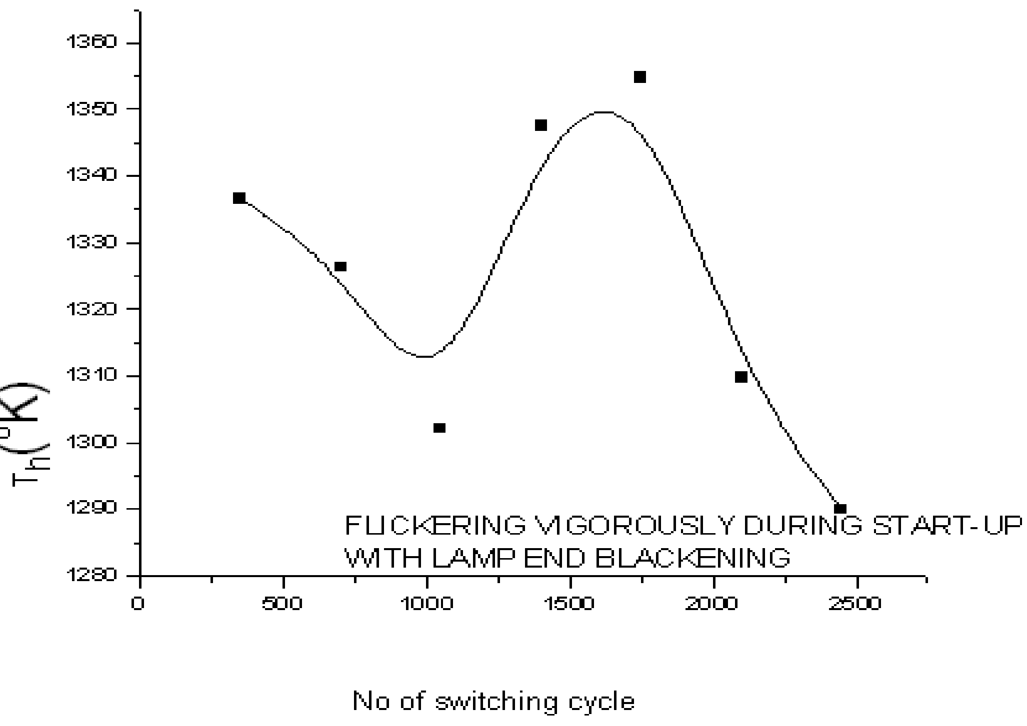

Fig. 12. Plot of T_h (°K) versus switching cycle for 15A CFL.

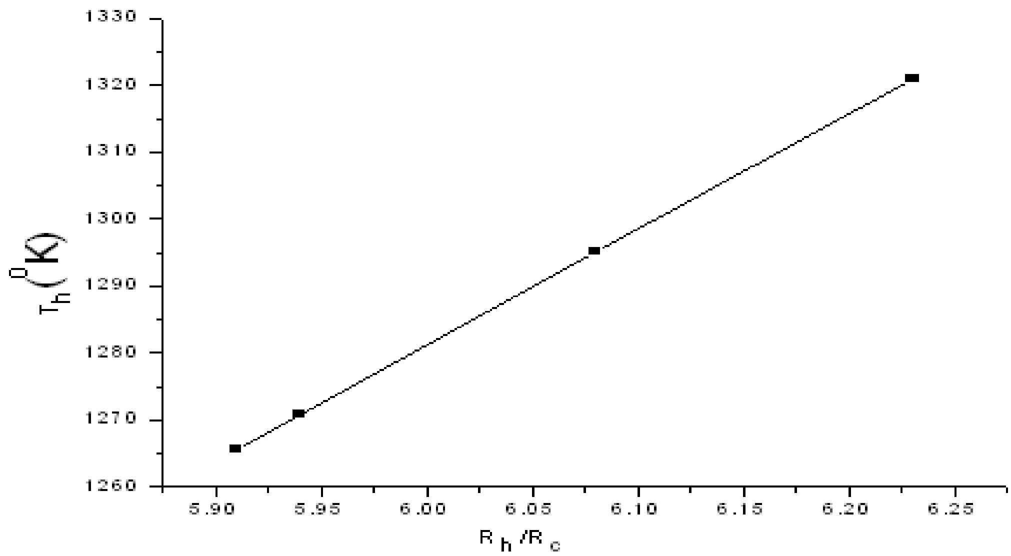

Fig.13. Plot of Th(K) versus Rh/Rc for 15A CFL.

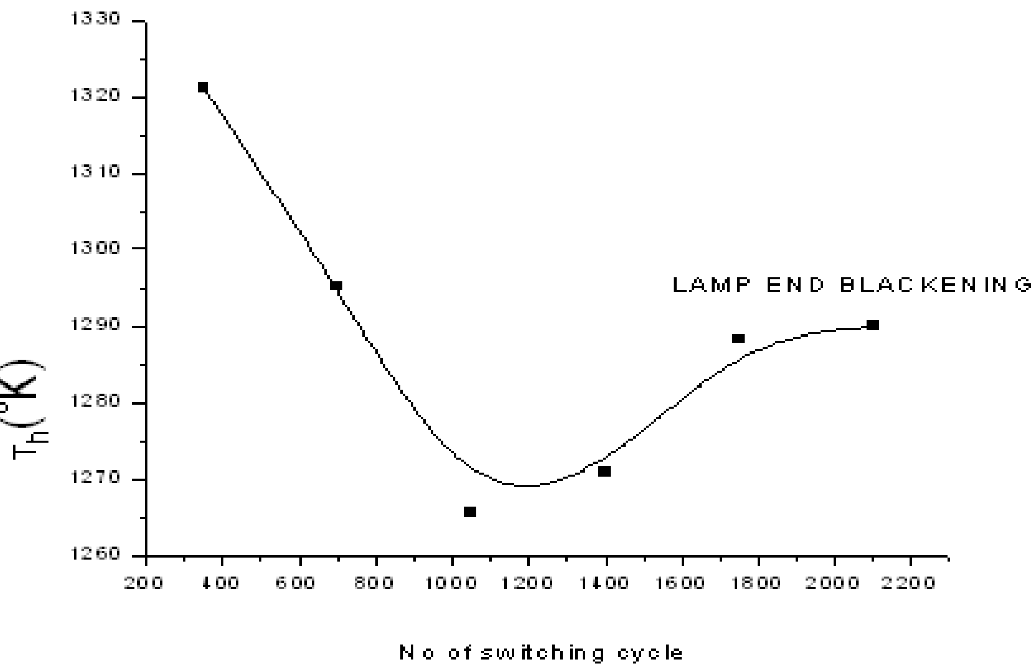

Fig.14. Plot of Th(K) versus switching cycle for 15A CFL

V. Conclusion

Thus from the above results it can be concluded that the self ballasted fluorescent lamps were sensitive to electrode temperature changes. Particularly for the lower wattage type of CFL a change in the electrode temperature from a reasonably high (around 1300°K) to a comparatively low value (around 1200°K) and the corresponding R_h/R_c ratio to 6.5 affected the lamp life. The reason may be assigned to the fact that a very high level of evaporation occurs at the high electrode temperature, thus burning out the lamp with subsequent switching. For the 18W lamps it was observed that, those lamps whose electrode temperature during start-up was around 1300°K fell to a lower value of around 1000°K to 1100°K before rising again. This phenomenon was observed for almost all the lamps of both 15W and 18W. This duration of temperature stabilization may be assigned as the period of ageing of the lamps. The rise in electrode temperature after the duration of ageing was seen to be steep apart for the lamp labeled as 15A. The temperature profile of the lamps under test depicted that for the 15W lamps a temperature rise to the extent of around 1300°K was responsible for excessive lamp end blackening while a temperature of around 1200°K was indicative of 18W lamp failure.

Secondly, the ballasts used for the lamps are of integrated and instant start type. This implies that the electrodes are not preheated and the power factors i.e. the input and the output, for these self ballasted lamps are invariably less than the recommended practice as per the IEC 61000-3-2[6]. Thus a lamp with a low output power factor is prone to draw in more current and hence the lamp electrodes are heated to a great extent. This factor is held responsible for a rise in electrode temperature of the lamp electrodes. Secondly, as the self ballasted lamps are of instant start type so the lamp electrodes are not preheated. Hence the electrodes are subjected to an electrical stress during each 'start' of the switching cycle which could also be a reason for the lamp failure. The results were applied to a total of eight numbers of samples, subjected to accelerated life test. The tests hence conducted offer an insight to the factors involving lamp life, particularly the electrode temperature profile.

The reason for such lamp failure may be related to the fact that the lamps those were tested had a very low output power factor (of around 0.65). This low output power factor were indicative of a very high lamp current and hence a subsequent increase of the lamp electrode temperature. It may therefore be concluded that the self ballasted fluorescent lamps with a low output power factor is prone to such rise of the electrode temperature and consequently a loss in lamp life. Moreover it is also an attempt to investigate the limiting electrode temperature a lamp could withstand before being burnt-out and the consequences on the R_h/R_c ratio. However more number of lamps may be considered for this study with different on and off times and different ballast circuitry.

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