

# Electrodeless Induction Lighting

Sourin Bhattacharya, Imran Hossain Sardar, Subarna Roy and Sudipta Majumder

**Abstract**— This paper reviews the current technology and usage trends of electrodeless fluorescent induction lamps and sulphur lamps. Induction lamps abide by the principle of electromagnetic induction. Visible light is generated by phosphor coating in case of fluorescent lamps and by sulphur molecules in case of sulphur lamps. The processes of light generation, spectral power characteristics, application areas, advantages and disadvantages in their utilization and the future scope of utility improvement are hereby briefly discussed and summarized.

**Index Terms**— Electrodeless Lamps, Sulphur Lamps, Discharge Lamps, Fluorescent Induction Lamps, Plasma Lamps, Horticultural Lighting.

## 1. INTRODUCTION

Induction lamps, ordinarily known as electrodeless lights, are usually high frequency (HF) light sources, which follow the rudimentary standards of changing over electrical energy into noticeable radiation by either electrostatic or electrodynamic methods of induction [1-3]. Sulphur lights utilize the previous [1] while fluorescent induction lights utilize the last [4]. The basic contrast between fluorescent induction lights and regular fluorescent lights is that the previous work without internal electrode terminals. The nonappearance of cathodes and anodes in induction lights improves the light life since the question of vaporisation of electrode materials does not arise. The basic premise of electrodeless induction lighting is the engagement of the principles of electromagnetic induction and light is generated by means of a vaporous release or gaseous discharge [5-7]. This section, section one, delineates the rudimentary light generation principles and types of induction lighting. Section two reviews relevant academic publications on induction lighting principles and characteristics. Section three reviews the technology regarding fluorescent induction lamps. Section four reviews the technology and development regarding light generation in sulphur lamps. Section five draws a comparison in a tabular form between fluorescent induction lamps and sulphur lamps regarding various lighting parameters and also mentions of the electromagnetic spectral power distribution (SPD) characteristics. Section six sheds light upon the application areas of induction forms of lighting and section seven concludes the review by summarizing the key points.

## 2. LITERATURE SURVEY

Turner, B. P. et al. [1] highlighted the energy conversion process in microwave sulphur lamps. The plasma could only allow visible radiation to exit the glass envelope owing to its optical depth. They observed the sulphur plasma, inside the glass envelope, fed by a microwave source of 3.4 kW rating and with appropriate RF shielding, producing 120 lumens of luminous flux per Watt of power consumed with a colour rendering index (CRI) of approximately 86. Coaton, J. R. et al. [2] described the broad principles of induction lighting in

general. Wharmby, D. O. [3] chronicled the historical development of electrodeless forms of discharge lighting and remarked that these light sources could become energy efficient and substitute tungsten-filament incandescent bulbs. Shaffer, J. W., and Godyak, V. A. [4] made experiments involving low frequency electrodeless lamps based on fluorescence. These lamps purportedly had long lives, high lumen output per unit power consumption, excellent system compatibility and photometric properties suited for general-purpose illumination. Shinomiya, M. et al. [5] developed an early prototype of an electrodeless fluorescent lamp of 25 W power rating and 1000 lumens light output. It was supplied with a supply voltage frequency of approximately 13.50 MHz. It was contended by the authors that it could instantaneously start glowing over a wide range of variation of environmental temperature. Hiebert, E. N. [6] described how the phenomenon of electric discharge through rarefied gases was investigated by Faraday, Plucker and Hittorf to further the scientific studies in this regard. Johnston, C. W., in two studies [7-8], the latter of which was made with other researchers, described molecular level mechanisms in sulphur plasma and found that the plasma temperature of around 4100 K rises slightly with increasing pressure and input power in high pressure microwave sulphur lamps. Other works [9-16] described the future aspects and prospective uses of electrodeless induction lamps in various fields and how these energy efficient lamps could be used in a variety of applications including wastewater treatment [13] and photochemical experiments [14,16]; it was emphasized that the growth of horticultural plants could definitely be facilitated by the usage of microwave (electrodeless) lamps [10].

## 3. ELECTRODELESS FLUORESCENT LAMPS

Certain types of fluorescent lamps rely upon the electrodynamic induction principle, a category of electromagnetic induction, to generate electromagnetic waves in the glass discharge tube and those lamps possess no contact terminals or electrodes in the aforementioned glass discharge tube [9].

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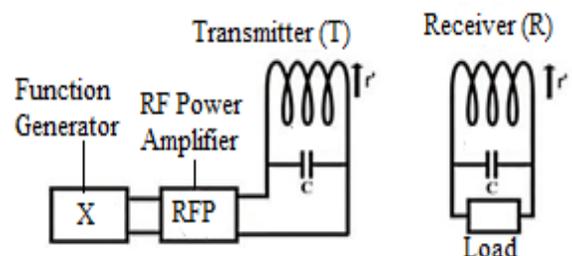


Fig. 1. Circuitry to Exhibit Electrodynamic Induction

Electrodynamic induction, also known as resonant inductive coupling, is a phenomenon in which two coils, coupled magnetically, transmit wireless electrical energy over close proximity when the coupled coils, as parts of resonant circuits, are at resonance at a specified frequency (**figure 1**). A resonant transformer having two high quality factor (Q) coils may exhibit this phenomenon when those two high quality factor (Q) coils are coupled as inductive-capacitive (LC) circuits with capacitances connected across the windings. Radio circuits may utilize resonant transformers as band pass filters. These may also be used in SMPS and wireless power transmission. In general, one such radio circuit may have two inductive-capacitive circuits, a transmitter coil in one part that transmits electric power over a short range to the receiver coil in another part that is at resonance with the transmitting part.

### I. External Coil Lamps:

In outer core fluorescent forms of induction lighting, a part of the gas discharge tube or cylinder is encircled by magnetic cores which are typically made of ferrite (**figure 2**). An electronic ballast supplies the input current to the lamp at a high frequency to generate a magnetic field within the discharge tube at a high frequency.

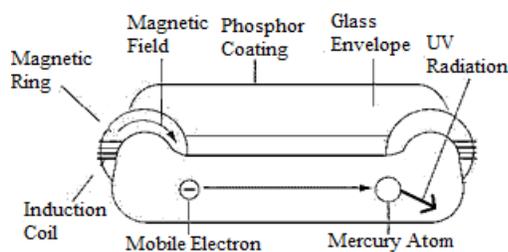


Fig. 2. External Coil Electrodeless Fluorescent Lamp

An alternating voltage is induced by the alternating magnetic field and it, in turn, energizes the mercury vapour contained within the lamp envelope, which produces electromagnetic radiation in the ultraviolet range. The inner phosphor coating, however, mostly absorbs the ultraviolet spectra and emits visible light, which is white to human eyes.

### II. Internal Coil Lamps:

A slender glass tube protrudes towards the globe of the bulb from the bottom of the discharge set-up in internal core fluorescent induction lamps (**figure 3**). This tube acts as a power coupler – a coil wound around a cylindrical core made of ferrite. This assembly of coil and ferrite core makes the inductive part, which in turn channels the supplied electric power to the inside of the lamp.

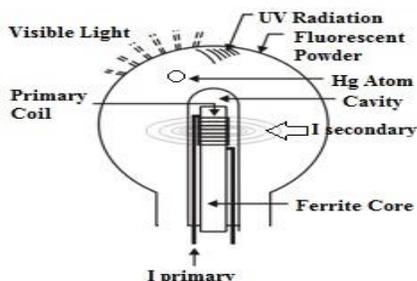


Fig. 3. Internal Coil Electrodeless Fluorescent Lamp

An electronic ballast supplies the input electric power at high frequency which is received by an antenna, which is an integral part of the set-up. Supply frequency may be variable but it is usually tuned at either 2.65 MHz or 13.60 MHz. A special purpose circuit within the ballast assembly generates a high voltage kick, which initiates the gas discharge in the tube; thereafter the power supply voltage is reduced to its safe and rated operating levels.

## 4. SULPHUR LAMPS

Sulphur lamps are excellent sources of electrodeless lighting. These lamps are highly energy efficient. In most sulphur lamp assemblies, a glass tube is filled with a fill material which may be a noble gas or a blend of noble gases and minute quantities of sulphur are added (**figure 4**). The sulphur lamp assembly is placed in a radio-frequency resonant cavity with parabolic reflectors. When the lamp starts operating, a starting gas is coupled with microwave energy and the fill material vaporizes. As the lamp envelope heats with progression of time, the vaporized fill material gets gradually excited by the microwave energy.

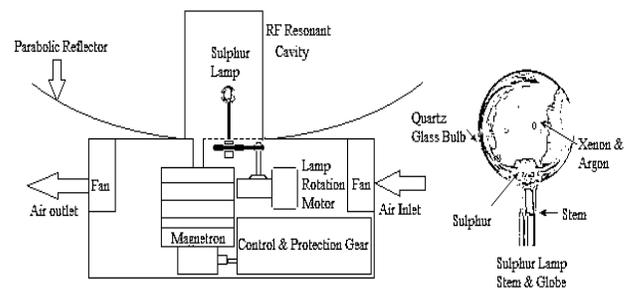


Fig. 4. A Typical Sulphur Lamp Assembly

The excited fill thus emits its characteristic electromagnetic spectra. In the sulphur lamp, the mechanism responsible for radiation, as proposed by Turner, B. P. et al. [1], is transitions from one excited state to another, namely from  $B^3\Sigma$  state to the  $X^3\Sigma$  state of the sulphur dimmer. Each transition may contain substructures owing to the superimposition of vibrational and rotational substructures on each electronic state. A typical sulphur lamp contains a fused glass bulb, made of quartz, containing sulphur powder [8] and xenon-argon noble gas mixture at the periphery of a thin spindle. The rotating bulb is typically placed and enclosed within a mesh that is microwave-resonant. A magnetron is used to bombard the rotating bulb principally with 2.40 GHz microwaves with the aid of a waveguide. Microwave bombardments transmit considerable energy to the gas elevating the pressure to around 5,00,000 pascal (Pa) and this promptly heats up the internal sulphur powder. This creates a plasma which glows very brightly and provides visible radiation. It is seen that the plasma temperature of around 4100 K elevates slightly with the increment in gas pressure and input electrical power to the lamp [7-8].

## 5. LIGHTING PARAMETERS

Lighting parameters such as correlated colour temperature (CCT), colour rendering index (CRI), luminous efficacy, lamp life and perceptible colours are tabulated herein:

Table 1: Lighting Parameters

Parameters	Electrodeless Fluorescent Lamps	Sulphur Lamps
Correlated Colour Temperature (CCT)	2800 K (Warm White), 3100 K to 3600 K (Neutral White), 4100 K to 4400 K (Cool White)	5500 K to 6000 K (White with Greenish Tinge)
Colour Rendering Index (CRI)	Average 50–85	Average 70-90
Luminous Efficacy	Average 45–65 lm/W	Average 70-80 lm/W (prototypes) and 90-100 lm/W (commercial)
Lamp Life	Estimated: 10,000 to 15,000 hours	Estimated: 40,000 hours
Perceptible Colours	Various Shades of White	White with Greenish Tinge

The spectral characteristics of electrodeless fluorescent and sulphur lamps are shown herein:

### I. Spectral Power Distribution of Sulphur Lamps:

The spectral output curve of sulphur lamps shows a local peak at 510 nm of wavelength in the visible spectra. The correlated colour temperature (CCT) may vary from 5500 K to 6000 K and the colour rendering index (CRI) may be as low as 70 or as high as 90, depending upon a number of factors. It may further attain a peak at 625 nm of wavelength as calcium bromide ( $\text{CaBr}_2$ ) impurities are often added to these lamps (figure 5).

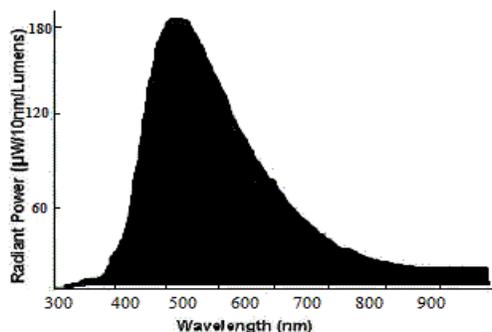


Fig. 5. SPD of a Microwave Sulphur Lamp

### II. Spectral Power Distribution of Cool White Electrodeless Fluorescent Lamps:

The spectral power distribution curve of cool white fluorescent induction lamps varies with the quality and quantity of used phosphor material and has prominent energy spikes at lower wavelengths (blue-green region, typically 450 nm to 560 nm of wavelength). The spectral power distribution of a typical cool white fluorescent induction lamp is shown below (figure 6):

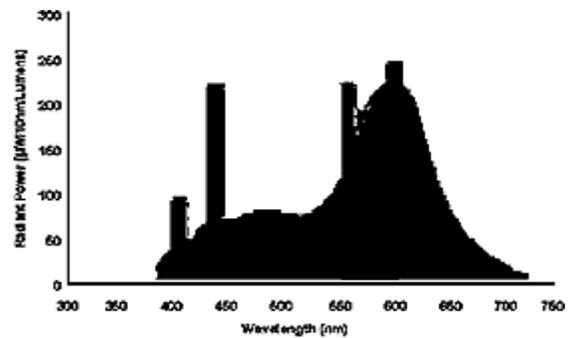


Fig. 6. SPD of a Cool White Electrodeless Fluorescent Lamp

### III. Spectral Power Distribution of Warm White Electrodeless Fluorescent Lamps:

The characteristic curve of these lamps demonstrates an increment in spectral energy at higher wavelength regions (usually beyond 560 nm of wavelength) and emit comparatively less energy in the blue-green region (typically 450 nm to 560 nm of wavelength) of electromagnetic spectrum. The spectral power distribution of a typical warm white fluorescent induction lamp is shown below (figure 7):

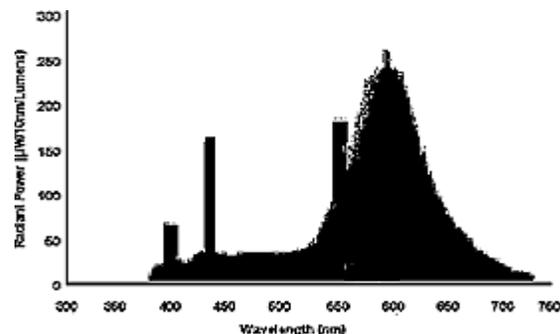


Fig. 7. SPD of a Warm White Electrodeless Fluorescent Lamp

## 6. APPLICATION AREAS

Sulphur lamps may be used as light sources for horticultural plants [10] and have potential to be utilized as light sources in large precision instruments. Microwave discharge electrodeless lamps can be used in wastewater treatment facilities [13]. In addition, electrodeless lamps may find usage in the field of photochemistry [14,16]. Sulphur lamps may be used in tandem with light pipes and secondary reflectors [17] as a means of assisting general daylight-integrated indoor illumination systems. Work has been done to utilize 1000 W sulphur lamps for indirect illumination systems [18]. Electrodeless fluorescent lamps are not as commercially successful as the conventional counterparts. Electrodeless forms of fluorescent lighting find usage in specialized small-scale lighting systems. These lamps have been utilized for monument lighting and analogue clock-face lighting and general lighting usages are still somewhat uncommon.

## 7. CONCLUSION

Induction lamps outlive their conventional counterparts mostly because there is no possibility of electrode material evaporation in discharge tubes. These lamps tend to show higher values of luminous efficacy (measured in lumens of luminous flux per Watt of consumed electric power or lm/W), low light output depreciation, consistent colour rendering [4]

and stable correlated colour temperature. Flickering and stroboscopic effects are usually not present in general operating conditions and these lamps may successfully replace tungsten-based incandescent forms of conventional lighting [12]. High power induction lamps have the potential to be incorporated in outdoor lighting systems as well. Nonetheless, their usages are still quite limited beyond decorative and creative purposes. Sulphur lamps are non-toxic and are shown to facilitate plant growth [10]. However, induction lamps have several drawbacks as well. Fluorescent induction lamps contain mercury, which is highly toxic to health and environment [11] and these lamps can cause radio-frequency interference to nearby telecommunication systems. Sulphur lamps are typically available in higher power ratings, require magnetrons, adequate control gear, radio-frequency resonant cavity, parabolic reflectors and active cooling systems. Thus, sulphur lamps practically would further require considerable installation space, complicated power system protection equipment and periodic maintenance. The advent and proliferation of LED lighting in both indoor and outdoor situations [19-22] have dimmed the future prospects of induction lamps, the existence and usage of such lamps are now somewhat limited to laboratory prototypes and expensive yet limited market releases. However, these lamps may find usage in the new and emerging fields of technology in near future.

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