Chapter 3
Atmospheric Pressure Plasma Systems and Applications

Necdet Aslan
Yeditepe University, Turkey

ABSTRACT

Atmospheric-pressure plasmas have a wide variety of potential industrial applications. They are used in extractive metallurgy; metal recovery; novel nanomaterial synthesis; refractory and wear-resistant coatings deposition; chemical synthesis; energy conversion; industrial, medical, and nuclear waste destruction; engine combustion enhancement; and exhaust gas pollutants clean up. Atmospheric plasmas are produced by applying DC or AC high voltage between two electrodes designed as cylindrical in shape for jets and planar for the dielectric barrier discharge systems. This review presents an overview of the use of atmospheric-pressure plasma devices and industrial processes carried out in several of these areas.

INTRODUCTION

The term plasmas are used in physics and chemistry to designate an ionized gas state and are considered the fourth state of matter. The term of plasma was proposed first time by Irving Langmuir in 1926. The plasma is a chemically active gas whose atoms or molecules are excited or ionized through thermal, reactive, electrical, and magnetic energy. The collective behavior of the plasma allows an equal number of free negative and positive charges leading to local quasi-neutrality. Plasmas consist of 99% of the physical matter in the universe (ionosphere, sun, auroras, solar winds, and other stars). Plasma is also artificially produced; several of them are part of our daily lives, such as monitors, LCD, television screens, as indicators in equipment,

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neon lamps or fluorescent tubes in lighting, etc. plasmas are also used as industrial proposals.

Plasmas are classified into two groups based on temperature: the thermal plasma (hot plasmas) and non-thermal plasma (cold) plasmas. Atmospheric pressure plasmas are classified based on local thermodynamics equilibrium (LTE). Generally, plasmas consist of electrons, ions, neutral atoms, and molecules occupying a collision-dominated region where the mean free path between the plasma species is short or large. This gives an increase to intensive chemical reactions by inelastic collisions and heavy particles heating by elastic collisions. In LTE between electrons and heavy particles to comparable temperatures, resulting in transitions and chemical reactions mainly governed by collisions. The non-LTE plasmas can be described by the difference in electron and heavy particle temperatures. This difference increases as the departure from LTE property is elevated; thus, the Boltzmann distribution for density for LTE plasma becomes non-valid (de Groot et al., 2018; Lotfy, 2017; Matra, 2016).

THE LOW-PRESSURE PLASMAS

This type of plasma is produced in a vacuum, where the mean-free paths between the plasma species are large. Consequently, the collisions between particles are not frequent. The electron temperature is higher compare to the heavy particles ($T_e >> T_h$) (Figure 2). In this type of plasmas, the density is low, a higher ionization rate, and local thermal equilibrium cannot achieve which causes cold heavy particles.

ATMOSPHERIC PRESSURE

This type of plasma produces nearly the same pressure as the surrounding pressure (normal pressure). Th**e** mean-free path among the plasma species is very short in this type of plasmas with collisions dominated regions. The LTE may be satisfied, including kinetic equilibrium between the species. This kind of plasma is also considered in chemical equilibrium such that species concentrations in LTE plasmas are only a function of temperature. The atmospheric pressure plasmas have two different types: such as thermal and non-thermal atmospheric pressure plasma. Glow discharge, high frequency with low-intensity discharge, and corona discharge are typical examples of cold plasmas. This type of plasma exists in various research fields, including physics, engineering, medicine, and biology (Shahzad, 2019; Shahzad & Bashir, 2019a; Shahzad & Bashir, 2019b; Shahzad et al., 2019).