Chapter 4

New Mechanisms for Cryogenic Solid–Gas Sublimation Refrigeration:
Basic Principles and System Designs

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ABSTRACT

Sublimation is one phase change mechanism which usually happens under low-to-moderate temperatures and at the same time large amounts of latent heat is absorbed or released. Low temperature sublimation has been proposed in a lot of applications as one useful fast cooling/refrigeration mechanisms, such as medical cooling, food engineering, chemical synthesis, domestic cooling and many industrial sectors. In this brief chapter, the basic mechanisms of static sublimation process and sublimation two-phase flows are clarified and analyzed first, which covers the theoretical and physical problems of sublimation phase-change. Then the previous studies are classified into numerical modeling and experimental verifications. Representative refrigeration systems are also introduced and compared in this chapter, which may give useful indications for future innovations in this field. Future research focuses are also summarized and proposed in this chapter.

INTRODUCTION

In recent years, sublimation flow and heat transfer has been proposed and utilized in real applications. Compared with traditional vapor-compression thermodynamic refrigeration cycles, using solid-gas sublimation flow can achieve more stable operation and probably higher heat recovery capacity, due to the relative high latent heat of sublimation process. Therefore, recently the investigation of solid-gas sublimation flows and its related application system designs has attracted a lot of research groups and engineer from both scientific world and industrial sectors (Robertson, 1932; Nelson, 1942; Lester & Somorjai, 1968; Eisenbraun et al., 1995; Michaelides & Lasek, 1987).

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Indeed, sublimation is one of the phase change mechanisms happening everyday in the world. As shown in Figure 1 (Aoki et al., 2002), dry ice sublimation is shown specifically for two different states when immersed in liquid tank. Early studies around 1930s have begun to investigate the basic thermophysical nature (Robertson, 1932; Nelson, 1942). At that stage, the main topics were set around the sublimation rate from the viewpoint of chemical reaction/engineering or chemical physics. Later, more groups have studied the thermal equilibrium and near-equilibrium sublimation process, which may assume the ideal condition of vacuum sublimation in order to obtain reasonable results with experiments.

As the sublimation substances such as Iodine, Naphthalene and Camphor were more and more used in domestic and engineering field, more studies came out since 1970s (Somorjai, 1968; Davy & Branton, 1970). However, the sublimation mechanism and physics behind what is seen is still unknown. At the same time, more studies has focused on the different factors that affect the sublimation rate of a crystal or particle, where the structural and chemical arrangements are analyzed from surface vaporizing to sublimation. Many groups have reported theoretical and experimental results measured for atomic crystal, molecular crystal, ionic crystal and others, under congruent or non-congruent sublimation process (Lester and Somorjai, 1968). Until recent years, there are still studies based on this general understanding of sublimation physics and the main focus on theoretical analysis and methods of numerical developments can be found (Schinzer & Kinzel, 1998; Smilauer & Vvedensk, 1995; Zhu et al., 2007; Krishnamurthy et al., 1990; Latyshev et al., 1996). The current review study will focus on the basic historic development of sublimation field and related cryogenic/refrigeration oriented applications in recent years.

However, the majority of those theories and experiments are based on strict assumptions of crystal structure and surface vaporization/sublimation laws (Somorjai & Lester, 1967). Large deviations are found between experiments and theoretical predictions, or from experiment to experiment. Since 1980s, with the development of social technology, sublimation flow related scientific and application studies

*Figure 1. Sublimation patterns of dry ice in liquid. (a) film-state sublimation (water of 25 ºC); (b) nucleate-state sublimation (ethanol of 17 ºC)*

(Aoki et al., 2002)
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