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A review on exergy analysis of drying processes and systems

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ABSTRACT

In recent years, growing attention has been given to exergy analysis of drying processes and systems and optimization of drying processes using exergy concept. This research interest is motivated by increasing the price of energies, environmental concerns, world population, decreasing fossil fuel recourses, and demanding for high quality dried products. Exergetic analysis provides a tool for a more realistic view between energy losses to the environment and internal irreversibilities in the process. The present literature review summarizes the using of exergy analysis in drying operations and facilities, discovers it benefits and abilities, and identifies prospects for future researches.

Contents

1. Introduction

The term drying or dehydration refers to removal of moisture from the solid or nearly solid material by evaporation under controlled condition [1]. Drying is perhaps the oldest method and most common form of food preservation employed by humankind [2–5]. It assures the microbial stability and guarantees the expected shelf-life of product; as well as provides the easier handling of product [6,7]. However, nowadays drying is not confined to the food industry. In industrialized world, drying is an essential operation in chemical, agricultural, biotechnology, polymer, ceramics, pharmaceutical, pulp and paper, mineral processing, and wood industries [8].

Traditionally, the Sun's energy was used for drying of agricultural and food products. It is the most widely practiced form of drying in the world because it is cheap, easy, and convenient.

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Nomenclature

Symbols

A	area, m^2
E	emissive power, kJ/s
ex	specific exergy, kJ/kg
$\dot{E}$	energy rate, kJ/s
$\dot{E}x$	exergy rate, kJ/s
F	shape factor
g	gravitational constant, m/s^2
g_c	constant in Newton's law
I	electric current, A
IR	radiation, W/m^2
$I\dot{P}$	improvement potential rate, kJ/s
J	Joule constant
$\dot{m}$	mass flow rate, kg/s
N	number of species
P	pressure, kPa
q	specific heat, J/kg
s	specific entropy, kJ/kg K
T	temperature, K
u	specific internal energy, kJ/kg
υ	specific volume, m^3/kg
V	velocity or voltage, m/s or V
w	specific work, J/kg
W	work rate, J/s
z	altitude coordinate, m

Subscripts

in	inlet
out	outlet
∞	dead state
c	chemical
$dest$	destruction
gen	generated
r	region

Greek symbols

μ	chemical potential, kJ/kg
ψ	exergetic efficiency

Even though Sun drying requires little capital or expertise, but there are many problems in using this method for drying of food products, such as undesirable changes in the quality of food products, being extremely weather dependent, aromas and vitamins loss due to direct sunlight, lack of sufficient control during drying, long drying time, contamination of the product with soil and dust, non-uniformity of dried products, and large space requirements, all of which necessitate using new technology in the drying process [9].

These problems could be overcome if artificial or industrial dryers are used. Nowadays, dryers have an important position in industry for processing and preservation of different foods and industrial material. More than 400 types of dryers have been reported in the literature amongst which solely 50 types are commonly used and readily available from various vendors. Drying is the most energy-intensive industrial unit operation due to the high latent heat of vaporization and the inherent inefficiency of using hot air as the most commonly applied drying medium. It consumes large amounts of energy and releases significant amount of carbon oxides to the environment [8]. Thus, one of the key issues of drying technology is to reduce the cost of energy sources to increase the efficiency of drying facilities for good quality of dried products. On the other hand, the design of an energy-intensive system for lower cost and higher efficiency is one of the essential approaches for sustainable development. Due to the high prices of energy, environmental concerns as acid rain and stratospheric ozone depletion, global warming, increased world population and decreasing fossil fuel recourses, the optimum application of energy and the energy consumption management methods are vital. Energy analysis is a basic and traditional approach to estimate various energy conversion processes [10].

The energy analysis is based on the first law of thermodynamics, which expressed the principle of the conservation of energy. However, it provides no information about the irreversibility aspects of thermodynamic processes. The energy analysis is unable to distinguish the different qualities of energy such as heat quality which is dependent on the heat source temperature. Due to these deficiencies and shortcomings of energy analysis, the exergy analysis which provides a more realistic view of the systems and processes has appeared a more powerful tool for engineering evaluations. Exergy is the maximum amount of work obtainable from a stream of matter, heat or work when some matter is brought to a state of thermodynamic equilibrium with the common components of natural surroundings by means of reversible processes, and is a measure of the potential of a stream to cause change, as a consequence of not being completely stable relative to the reference environment [11–14]. The exergy analysis can provide comprehensive and deeper insight into the process and new unforeseen ideas for improvements, and therefore it is applicable for the processes evaluation and optimization purposes. It is however noteworthy that the exergetic performance assessments not only distinguishes the magnitudes, location and causes of irreversibilities in the plants, but also enables the engineers to recognize the individual components efficiency of plant [15,16]. The exergy based performance evaluation and subsequent optimization of drying facilities have been a growing interest among the researchers in recent years. It is noteworthy that the suggested strategies based on exergy concept or energy analysis to improve the system efficiency are quite different. The main objective of exergy analysis of drying systems is to provide a clear picture of the process, to quantify the sources of inefficiency, to distinguish the quality of energy consumption, to select optimal

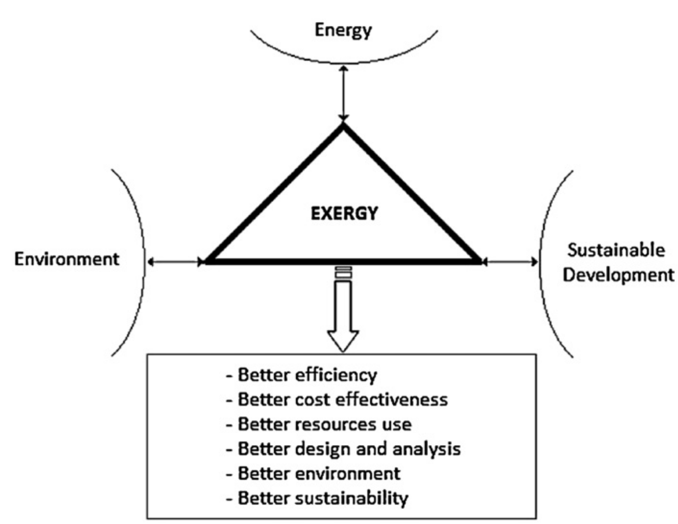

Fig. 1. The interdisciplinary triangle of exergy [17,18].