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Journal of the Franklin Institute 351 (2014) 878–906

Journal of The Franklin Institute

www.elsevier.com/locate/jfranklin

Characterization of chaotic multiscale features on the time series of melt index in industrial propylene polymerization system

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Received 16 January 2013; received in revised form 18 September 2013; accepted 20 September 2013
Available online 7 October 2013

Abstract

The chaos characteristics of melt index have been first explored, and the Hilbert–Huang transform method and time delay embedding method are applied to multiscale dynamic analysis on the time series of the melt index (MI) in the propylene polymerization industry. The research results show that the embedding delay is 2, the embedding dimension is 5, the correlation dimension D_2 is 1.57, and the maximum Lyapunov exponent is 0.143 for the melt index series, which provide clear evidence of chaotic multiscale features in the propylene polymerization process. Three intrinsic mode functions (IMFs) are decomposed from the melt index time series; the presence of non-integer fractal correlation dimension and positive finite maximum Lyapunov exponent are found in some IMF components. The PP melt index series are divided into two chaotic signals, a determined signal and a random signal respectively, and its complexity is therefore reduced. Furthermore, the coupling of subscale structures of the propylene polymerization is explored with the dimension of interaction dynamics and a robust algorithm for detecting interdependence. It is found that IMF(2) is the main driver in the coupling system of IMF(1)and IMF(2). All these provide a guideline for studying propylene polymerization process with chaotic multiscale theory and may offer more candidate tools to model and control propylene polymerization system in the future.

Keywords: Melt index prediction; The Hilbert–Huang transform method; Time delay embedding method; Multiscale dynamic analysis; Propylene polymerization industry

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0016-0032/$32.00
http://dx.doi.org/10.1016/j.jfranklin.2013.09.022

Nomenclature

$x(t)$	the original time series of the melt index
$c_j(t)$	the IMFs
$r_j(t)$	the residual series
$h_i(t)$	the iterative transition sequences
$m(t)$	the mean of the upper and lower envelopes
$c_1,\ c_2,\ c_3$	the three IMFs
r_3	the residual
ε	the stopping criteria
PV	the principal value of the singular integral
$a_j(t)$	the instantaneous amplitude
$\varphi_j(t)$	the phase function
$\omega_j(t)$	the time derivative of $\varphi_j(t)$
$V(S)$	the set of all the substring of the sequence S
COM	the Lempel–Ziv complexity
τ	the time delay
$I(\tau)$	the mutual information between $x(t)$ and $x(t+\tau)$
$P(x(t))$	the normalized distribution of $x(t)$
$P(x(t+\tau))$	the normalized distribution of $x(t+\tau)$
$P(x(t), x(t+\tau))$	the simultaneous distribution
m	the embedding dimension
r	the selected radius
$H(x)$	the heaviside function
D_2	the correlation dimension
$R_d^2(k)$	the Euclidean distance between $s(k)$ and $s^{NN}(k)$
R_{tol1}	the judgment criterion of the 'false' neighbor point
R_{tol2}	the another judgment criterion of the 'false' neighbor point
λ_1	the maximum Lyapunov exponent
$r_{n,j}$	the time indices of the jth nearest neighborhood point of X_{an}
$s_{n,j}$	the time indices of the jth nearest neighborhood point of X_{bn}
$wmean$	the averaged instantaneous frequencies

1. Introduction

The industry of polypropylene (PP) production has a critical influence in the world, especially in aspects of related industries, military, economy, and so on [1–3]. The increasing global competition pushes the polymer industry to improve the product quality and reduce the cost. Consequently, the advanced monitoring and controlling of the properties of the products in PP process becomes a very important strategy in this field. PP melt index (MI), which is the key parameter in determining the product's property and quality controlling of practical industrial process, is defined as the mass rate of extrusion flow through a specified capillary under certain condition of temperature and pressure [2]. Certain instruments are developed to measure the MI directly, but these instruments are very expensive and difficult to maintain. Therefore, the PP is