

increased safety and improved control, and/or combines multiple operations into a single or fewer devices.⁵ Moreover, Hessel⁹ emphasized that PI needs to be distinguished from (i) process optimization, defined as performance improvement of existing concepts, and (ii) process system engineering, defined as multi-scale integration of existing and new concepts using PI as a “provider of building blocks” from which process systems are further developed (Table 7.1).^{7,9}

Beyond a mere PI definition, van Gerven and Stankiewicz⁷ have defined the fundamentals of PI according to four basic principles, so called domains: ‘time’, ‘space’, ‘function’, and ‘energy’. Wang *et al.*¹¹ further defined these principles with respect to the unit operation crystallization (Table 7.2) but did not distinguish particularly between batch and continuous processing.

Continuous crystallization, as outlined in previous chapters of this book, is already one approach to PI within the time domain (Table 7.2). This chapter, however, focuses on the application of PI from all four domains to the concept of continuous crystallization because PI can also be obtained using batch crystallization processing.^{3,11} Although it becomes obvious that each concept in Table 7.2 contains elements of multiple PI domains,

Table 7.1 Definitions and descriptions of process optimization, process systems engineering, and process intensification.⁹

	Process optimization	Process systems engineering	Process intensification (PI)
Aim	Performance improvement of existing concepts	Multiscale integration of existing & new concepts	Development of new concepts of process steps & equipment
Focus	Model & numerical methods	Model, software	Experiment, phenomenon, interphase
Interdisciplinarity	Weak <i>Applied mathematics</i>	Modest <i>Chemistry, applied mathematics, and informatics</i>	Strong <i>Chemistry, applied physics, materials design, chemical & mechanical engineering, automation, etc.</i>

Table 7.2 Fundamental principles of process intensification (PI) for continuous crystallization.¹¹

Time domain	Space domain	Function domain	Energy domain
Continuous operation	Structure	Hybrid processes	External fields
<ul style="list-style-type: none"> ● MSMPR ● PFC 	<ul style="list-style-type: none"> ● Static mixers ● Segmented flow ● OBC 	<ul style="list-style-type: none"> ● Chromatography ● Membrane ● Distillation 	<ul style="list-style-type: none"> ● Ultrasound ● Electric ● Microwave
Periodic operation	Miniaturization	Process integration	
<ul style="list-style-type: none"> ● Temperature cycling ● Periodic flow 	<ul style="list-style-type: none"> ● Porous materials ● Patterned surfaces ● Emulsions ● Microfluidic crystallizers 	<ul style="list-style-type: none"> ● Spherical crystallization ● Wet milling ● Multifunctional equipment 	