Technical
Report

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Automation systems and integration — Integration of advanced process control and optimization capabilities for manufacturing systems —

Part 4:
Application for distillation process

Systèmes d'automatisation et intégration — Intégration de contrôles de processus avancés et capacités d'optimisation des systèmes de fabrication —

Partie 4: Application pour le processus de distillation

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Foreword

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This document was prepared by Technical Committee ISO/TC 184, *Automation systems and integration*, Subcommittee SC 5, *Interoperability, integration, and architectures for enterprise systems and automation applications*.

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Introduction

As a crucial part of the increasingly complex manufacturing systems, automation and control applications which are enabled by advanced process control and optimization (APC-O) methodology and solutions are implemented under the direction of production planning and scheduling. This task involves initially the specific use of APC-O that will enable the integration of manufacturing operations management (MOM) with the automation and control of manufacturing process and equipment.

Automation solutions equipped with both software and hardware components are provided by different suppliers to accomplish APC-O functions. Due to the diversity of development environments and the variety of demand focus, the automation solutions from various suppliers tend to be isolated and relatively independent, which make it harder for the automation solutions to be integrated. Consequently, various automation solution components that the customers can have access to would be filled with redundant and duplicated functions, resulting in a waste of resources and limited interoperability. The proposed standard offers a reference interoperability framework for advanced process control and optimization with the intention of maximizing both the integration and the interoperability of automation solutions.

It is not the intent of this document to suggest that there is only one way of implementing APC-O or to force users to abandon their current way of implementing APC-O.

The target users of this document include: users and providers of advanced process control and optimization solutions, such as project solution suppliers, automation systems integrators, production departments of companies, process engineers, independent software testing organizations, implementation and consulting service organizations of advanced process control and optimization software, and relevant government and academic organizations.

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Automation systems and integration — Integration of advanced process control and optimization capabilities for manufacturing systems —

Part 4:
Application for distillation process

1 Scope

This document describes a solution for integrating advanced process control and optimization capabilities for manufacturing systems by introducing the advanced control system of the distillation column in detail with a separate distillation column as an application case.

This document is intended to be used with ISO 15746-1, ISO 15746-2 and ISO 15746-3.

2 Normative references

There are no normative references in this document.

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3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at https://www.electropedia.org/

3.1
advanced process control
APC
control strategy to cope with processes characterized by large time delays, non-minimum phase, non-linearity, loop instability and multi-variable coupling

Note 1 to entry: APC enhances basic process control by addressing particular performance or economic opportunities in the process.

EXAMPLE MPC, Adaptive control, Inferential control.

3.2
advanced process control and optimization
APC-O
collection of advanced process control and optimization strategies

3.3
workflow
sequence of activities with explicit starting and ending points to describe a task

Note 1 to entry: Workflows can also have branches, decision points, and events. A workflow is a type of activity model.

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3.4
checkpoint
point where *verification* (3.9) and *validation* (3.8) activities needed to be performed throughout the APC-O lifecycle

3.5
indicator
measurement of an aspect of the system or component

Note 1 to entry: There are two types of indicators: *quantitative indicators* (3.6) and *judgement indicators* (3.7).

3.6
quantitative indicator
indicator (3.5) that is calculated using the physical formula

3.7
judgement indicator
indicator (3.5) that is evaluated using the evaluation method

3.8
validation
process of evaluating an APC-O system to determine whether it satisfies the stakeholders' requirements for that system

3.9
verification
process of evaluating an APC-O system to determine whether the output of a phase satisfies the conditions imposed at the start of that phase

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4 Analysis of the distillation process

4.1 Introduction to the distillation process

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Distillation is one of the most common unit operations in the chemical industry. Unfortunately, the research on distillation has repeatedly been proclaimed to be a dead area, and some universities have even considered to stop teaching the basics of McCabe-Thiele diagrams. However, there have been renewed interests for the distillation process in recent years, mainly because the topic of distillation column has become a favourite subject in the field of process systems engineering, including process synthesis, process dynamics and process control. The distillation column itself is a system that can be viewed as a set of integrated, cascaded flash tanks. However, such integration gives rise to a complex and non-intuitive behaviour, resulting in a more challenging problem. The difficulty lies in understanding the behaviour of the whole system (the distillation column), based on the given knowledge of the individual pieces (the flash tanks).

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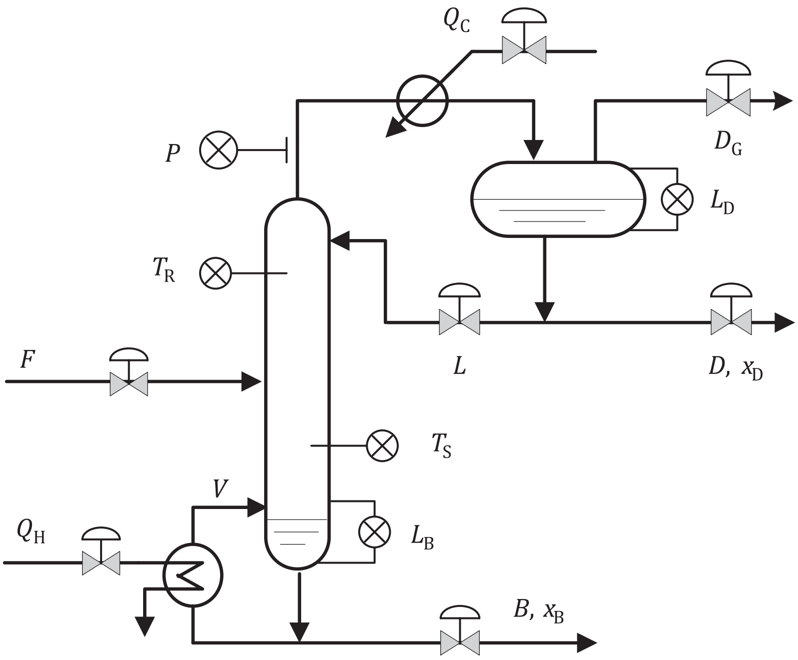

Figure 1 — Sketch of the distillation column

Table 1 — List of the variables in a typical distillation column

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Name	**Definition**
F	Feed flowrate [kmol/min]
$D,\ B$	Distillate (top) and bottoms product flowrates [kmol/min]
x_D, x_B	Distillate and bottom product compositions (usually of light component) [mole fraction]
L_D, L_B	Condenser liquid level and bottom liquid level [m]
T_R	Sensitive plate temperature [K]
P	Top pressure [kPa]
Q_H	Heat flowrate [kmol/min]
Q_C	Cooling flowrate [kmol/min]
$L = L_T = L_{N_{tot}}$	Reflux flow [kmol/min]
$V = V_B = V_1$	Boilup flow [kmol/min]
N	Number of theoretical stages including reboiler
$N_{tot} = N + 1$	Total number of stages (including total condenser)
i	Stage number (i = 1 refers to the bottom stage; $i = N_F$ refers to the feed stage)
L_i, V_i	Liquid and vapor flow from stage i [kmol/min]
x_i, y_i	Liquid and vapor composition on stage i (usually of light component) [mole fraction]

A typical two-product distillation column is shown in Figure 1. The most important notations are summarized in Table 1 and a typical example of control loops for the distillation column is given in Table 2, in which index i is used to represent the stage number, and the stages are numbered from the bottom ($i = 1$) to the top ($i = N\text{tot}$) of the distillation column. Index B represents the bottom product and the distillate product. Index j is used to represent the components; $j = L$ refers to the light component, and $j = H$ refers to the heavy component. Note that it usually refers to the light component, when there is no component index.

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4.2 Control and optimization

4.2.1 Regular control system analysis

A typical example of conventional control system for the distillation column is shown in Figure 2.

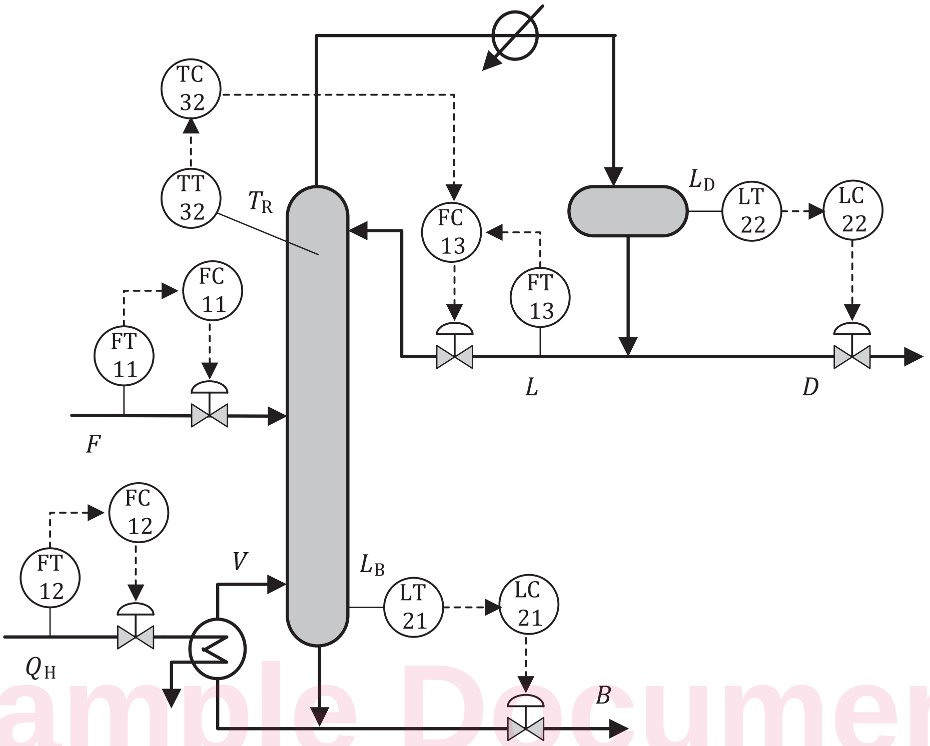

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Figure 2 — Typical example of conventional control system for the distillation column

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Table 2 — Typical example of conventional control loops for the distillation column

No.	Loop	Loop description	Control type
1	F	Feed flowrate	Regular control
2	L	Reflux flowrate	Regular control
3	T_R	Sensitive plate temperature	Cascade control
4	L_D	Condenser liquid level	Regular control
5	L_B	Bottom liquid level	Regular control
6	Q_V	Heat flowrate	Regular control

An example of conventional control loops for the distillation column is shown in Table 2.

The following problems often occur in the regular control system running process:

a) The abrasion that results in the decline or even the failure of the operation of control system will affect the normal production process.

b) During the online operation process, the increase of measurement noise or even the failure of measuring instruments will affect the regular production process.

c) The regular control system based mainly on proportional-integral-derivative (PID) law cannot effectively solve the problems of large time delay and strong in the actual production process.

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Apart from the above problems that are needed to be addressed during the daily operation of the plant, there is also pressure as the result of the market competition. In response to the ever-changing market price and demand, the need to continuously reduce the production cost and improve the operation efficiency of the plant becomes inevitable and that is why the automation of plant operation becomes a key issue.

4.2.2 Soft sensor and state estimation

In the practical application of distillation column, the main measurement of conventional instrumentation system includes the flow, the level, the pressure, and the temperature without the on-line measurement of product quality. Due to the high cost of installing and maintaining an on-line quality analyser, the post-test inspection can only be carried out through laboratory tests during the actual operation which is characterized by a long laboratory testing cycle for about twice a day. For the above reasons, it is impossible to obtain the real-time product quality variables during the production process, which will inevitably make an impact on the production operation of the device.

4.2.3 Advanced process control

With reference to the regular control system, the closed-loop control cannot be achieved because of the mechanism characteristics of the plant production process, the large time delay and the coupling between the top temperature TD and bottom temperature TB. To deal with changes in output and production demands, the operator needs to take a series of actions to switch between various working conditions, which requires the advanced process control techniques.

4.2.4 Real-time optimization

Real-time optimization module implements the instruction from the scheduler to automate the production process: in the case of meeting the needs of production management, the goal of operating the device automatically can be achieved while maximizing the benefits.

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5 Technical scheme

5.1 Technical framework for the distillation column APC-O system

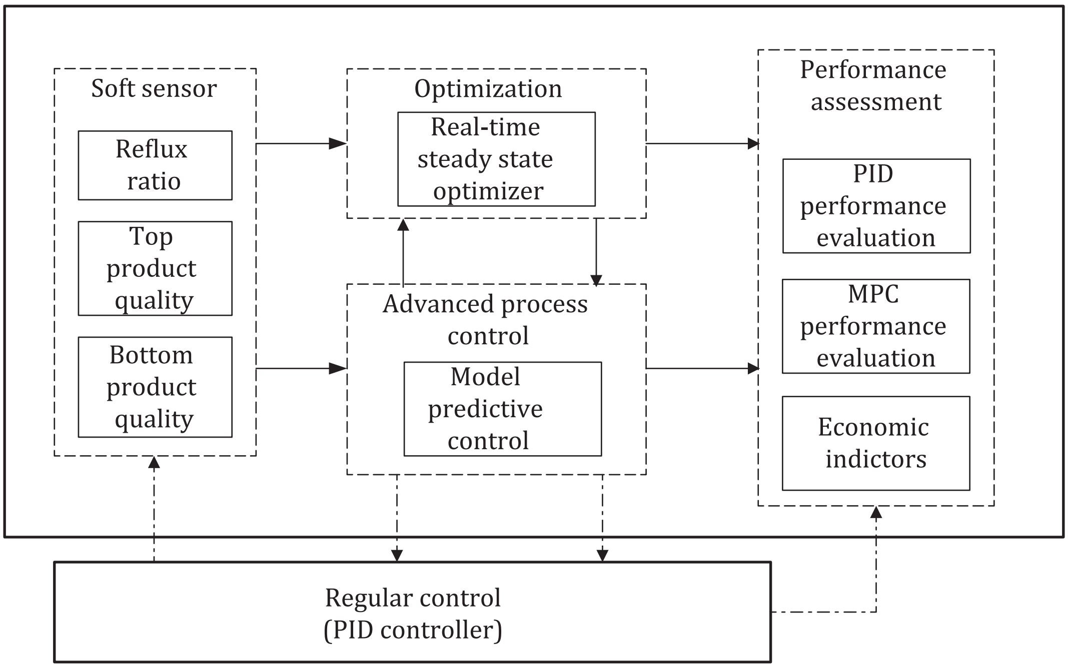

Figure 3 — Technical framework of a typical APC-O system for the distillation column

As it is defined in ISO 15746-1, ISO 15746-2 and ISO 15746-3, a typical framework of APC-O system mainly contains the following four parts:

a) Soft sensor: Indirectly calculating the unmeasured key indicators and variables such as the reflux ratio, the product quality at the top and bottom of the distillation columns.

b) Multivariable model predictive control: Enabling smooth running and operation of the device using model predictive controller(s), so that the measuring indicators, such as the liquid level and the temperature of the device, can be steadily controlled around their predefined setpoints.

c) Real-time optimization: Automatically maximizing the benefits of the production process, with respect to the system constraints related to the scheduling commands, the product prices, and the material costs, etc.

d) Performance Evaluation: Evaluating and monitoring the performance of the basic PID control loops, APC control loops, optimizer as well as monitoring the key economic indicators.

The technical framework of a typical APC-O system for the distillation column is shown in Figure 3.

5.2 Soft sensor

For the demand of product quality measure as well as avoiding the high cost of online quality analysis instruments, the soft sensor instruments are set up to predict the real-time product quality in an online manner. The specific variables to be measured in the distillation column APC-O system are listed in Table 3.

Table 3 — Variables to be measured in the distillation column APC-O system using soft sensor

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No.	Name	Description	Target
1	X_B	Top product quality (concentration)	
2	X_D	Bottom product quality (concentration)	
3	R_R	The ratio of the reflux flow L to top product flow rate D in the column top return column, $R = L/D$	

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Soft sensor instrument establishes a soft sensor model using the available historical data and performs the real-time prediction online. Moreover, the soft sensor instruments eliminate the deviations during the online prediction process through the ground-truth laboratory analysis data.

5.3 Advanced process control

Table 4 describes a typical example of the process variables in the APC module using multivariable predictive control. Table 5 describes the predictive models in the multivariable predictive controller for the distillation column.

Table 4 — Typical example of process variables in the APC system of the distillation column

Process variables: MV\DV\CV			
	Name	**Description**	**Target**
MV	L	reflux flow	Minimum movement control
	V	boilup flows	Minimum movement control
DV	F	feed flowrate	
	Q_H	Heat flowrate	
CV	T_R	sensitive plate temperature	Setpoint control
	T_D	bottom temperature	Setpoint control
	R_R	reflux ratio	Lower limit control

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