*This study considers a CIP station used for automated cleaning of process equipment in the food industry. The task addressed relates to the lack of a formalized methodology for decomposing a CIP station that would enable the construction of object-oriented control models in accordance with international standards.*

*The result of this study is the devised methodology for CIP station decomposition based on the principles of IEC 61512, which includes the identification of the levels of process cell, process units, equipment modules, as well as control modules. It has been shown that this approach allows for a structured representation of the equipment and its functions, enabling the integration of technological steps with the equipment of the CIP station.*

*The results are attributed to the fact that the CIP cleaning process has a hierarchical structure and procedural repeatability, which allows it to be formalized as a set of interrelated levels – from the process cell to individual equipment modules. This feature ensures consistency between the process logic and the physical structure of the equipment, which enhances the efficiency of control. A distinctive feature of the results is the combination of hardware hierarchy with information models, which differentiates the proposed solution from conventional descriptive approaches. This not only improves the flexibility and scalability of control systems but also creates conditions for building libraries of reusable software objects.*

*The results could be practically implemented at industrial enterprises in the food, pharmaceutical, and chemical industries where CIP stations are used. They could be integrated into current SCADA/PLC systems using AutomationML and OPC UA standards, ensuring compatibility with MES/ERP levels of control. This improves the efficiency of equipment operation while reducing the costs for designing and maintaining automation systems*

***Keywords:*** *CIP station, IEC 61512, object-oriented control, decomposition, process cell, process unit*

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# CLEANING-IN-PLACE STATION DECOMPOSITION FOR OBJECT-ORIENTED CONTROL

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## 1. Introduction

Modern food, pharmaceutical, and chemical production require a high level of automation of technological processes, which enables product stability, safety, and efficient use of resources. One of the critically important elements of such processes is the washing of technological equipment using CIP stations, which provide automated cleaning of equipment without the need for its disassembly. Despite the widespread use of CIP stations, there are a number of problems associated with their integration into the automation systems of the entire production:

– complexity of control. Conventional approaches to control are often based on sequential algorithms of operation, which complicates the modification and scaling of the system, as well as coordination of work with other technological equipment;

– low flexibility due to the lack of reuse of components. CIP stations are quite typical technological equipment. However, without a clear structuring of the equipment and its control logic, it is difficult to reuse the designed CIP stations in different processes or projects. This leads to high costs of adapting systems to new production requirements;

– lack of an object-oriented approach. Current automation standards, such as IEC 61512 (ISA-88), provide for the use of an object-oriented framework for modeling equipment and procedures. However, in practice, most CIP stations are controlled using algorithms without a clear division into objects, which complicates the integration, testing, and scaling of the system.

Thus, scientific research into this area is important because in this context, the decomposition of a CIP station and the construction of equipment models is a key step for implementing object-oriented control.

## 2. Literature review and problem statement

In the scientific and technical literature, the issues of construction and operation of CIP stations are considered mainly from the point of view of cleaning technology, choice of cleaning solutions, energy efficiency, and ensuring sanitary standards [1]. Considerable attention is paid to improving the quality of surface cleaning, optimizing water, steam, acid, and alkali consumption, as well as devising effective cleaning programs, but the authors do not deal with the problem of effective organization of the control system.

In paper [2], a tendency is noted in the study of methods for integrating CIP stations into general production control systems. However, the research focuses mainly on individual technical solutions and does not form a holistic approach to modeling and controlling CIP stations.

Another problem noted in scientific and applied studies is that in most cases control is carried out on the basis of simple algorithms. Such algorithms do not provide for a clear division of functions. For example, the authors of study [3] consider the CIP stations as an object that does not have a hierarchical structure, and in the process of control directly interact with sensors and actuators. This complicates the design of the control system and the integration of CIP stations into complex production systems and limits the functionality of reusing solutions.

Another issue noted in the scientific literature is the lack of a unified approach to the classification of control objects and their components. Work [4] reports the results of research in the field of using the methodology for building a control system hierarchy for object-oriented PLC programming. It is shown that modularity and structuring of logic significantly simplify the development of control system software. However, the issues of applying this methodology to CIP stations remain unresolved; in addition to functional modularity, hierarchical decomposition of equipment is required in accordance with the implementation of scenario control. The reason is the focus of the work on the general principles of PLC programming, and not on the specific features of batch production. The difficulties can be overcome by combining the approaches proposed by the authors with the representation of the CIP station as a technological cell, as provided for by the IEC 61512 standard.

The international standard IEC 61512/ISA-88 defines the principles for building models of technological equipment and control procedures for batch production. The authors of papers [5, 6] have proven that its application provides unification of process descriptions, flexibility, and scalability of systems, and the possibility of reusing software and technical solutions. However, the issues of applying the provisions of IEC 61512 to build a control system for CIP stations remain unresolved. IEC 61512/ISA-88 sets an established approach to hierarchical decomposition of equipment and procedural modeling of recipes in batch production control. The standard provides conceptual rules and terminology, which makes it a natural basis for object-oriented models in industrial automation. At the same time, the standard provides general principles but does not contain specific methods for transforming a real technological device (for example, a mixer or pasteurizer) into a specific set of hierarchy elements.

The authors of [7] provide an analysis of the current state of production in the chemical industry. They showed that modularity and standardization can significantly increase flexibility and reduce the time for implementing new technologies. However, the issues of formalizing equipment decomposition remain unresolved: there is no clear methodology for transforming real technological blocks into standardized modules for further use in control systems. The reason is the predominantly strategic nature of the work (trend review), without deep methodological detailing. Overcoming these limitations is possible by devising decomposition rules in accordance with IEC 61512/ISA-88, which would form the basis for object-oriented control.

The IEC 61512/ISA-88 standard is not the only one that describes the structures for building hierarchical models of control systems. Similar guidelines are also given in the IEC 61499 standard, but the control system is considered from a different angle. In study [8], the application of the IEC 61499 standard and service-oriented architectures for building distributed control systems is considered. The authors propose a modular model of the control system, which provides the possibility of dynamic reconfiguration of the system and reuse of its components. This is useful for modular installations, in which modules can be added or removed. However, these solutions focus on the level of software services and communications; without a clear decomposition of the equipment, as defined by IEC 61512, a gap arises: it is not clear which physical elements should provide which services, and which module boundaries are most correct.

Also, for building hierarchical models of the control system, one can use the AutomationML and OPC-UA specifications. AutomationML and OPC-UA are the keys to formalizing the information model of the equipment and integrating control modules into the general information infrastructure of production. Studies [9, 10] show the possibility of automatic generation of OPC-UA information models from AutomationML and the advantages of unifying device semantics. The problem is that specific profiles (for example, for heat exchangers, dosing pumps, collectors) are not yet standardized to a sufficient extent; and without decomposition methods, building such models is complicated. This directly concerns the decomposition of the physical model of the equipment: each control module and other element of the hierarchical model must have its own information profile.

All above sources demonstrate progress in the field of object-oriented, modular, and comprehensive approaches to automation. However, none covers the in-depth decomposition of a CIP station as a technological cell with the identification of technological nodes, equipment modules, and control modules, in accordance with the IEC 61512 standard. Thus, it is advisable to conduct a specific study on the object-oriented decomposition of a CIP station in accordance with IEC 61512.

## 3. The aim and objectives of the study

The purpose of our study is to decompose a CIP station, which makes it possible to build an object-oriented equipment model compatible with the IEC 61512/ISA-88 standards. This will make it possible to increase the flexibility of the technological equipment, simplify the setup and modification of cleaning programs in the future, and ensure compliance with modern standards of automation and integrated production.

To achieve the goal, the following tasks were set:

– to define criteria on the basis of which the objects of the equipment model hierarchy are identified;

– to build a model of the equipment of a CIP station, in accordance with the principles of the IEC 61512 standard, with the identification of the basic components;

– to construct a model of the technological process of a CIP station with division into basic elements;

– to devise recommendations for implementing object-oriented control in CIP stations to improve efficiency of the technological equipment.

## 4. The study materials and methods

The object of our study is a CIP station, which is used for automated cleaning of technological equipment in the food industry. The principal hypothesis of the study assumes that the application of the principles of equipment decomposition in accordance with the IEC 61512 standard provides the possibility of building object-oriented models of control systems. Such systems are more flexible, scalable, and reusable in various production systems.

The IEC 61512 standard is focused on batch production. Therefore, the following assumptions are adopted that bring the CIP station closer to the IEC 61512 objects:

1) cleaning is a periodic process that has a scenario, route, start, stop, and must be uniquely identified; therefore, each wash has all the properties of a batch except for difference 1;

2) the wash scenario is considered a scenario for preparing a Batch, defined in the standard;

3) the role of the equipment being washed in the production is not taken into account and is considered low-level; all the features of the washer are taken into account in the washer scenario;

4) the technological processes for the washer are the processes of physical and chemical cleaning in the stream.

The study accepted a number of simplifications:

1) the model does not take into account the real physicochemical characteristics of the cleaning process (temperature, concentration, reaction rate), since the study focuses on the structural representation of the process, and not on its dynamic modeling;

2) the study does not take into account external factors related to the production environment (e.g., cleaning schedule, line loading, logistical delays), since the model is focused on the internal structure of the CIP station;

3) cleaning procedures are described as typical stages without taking into account variations in recipes or technological parameters, since the structure of the CIP station is studied, and not the optimization of technological process parameters.

The methodological basis of the study is the theoretical methods of system analysis, structural modeling, and hierarchical decomposition. To describe objects and their relationships, the provisions of the international standard IEC 61512 (ISA-88) are used, which sets the principles for building models of technological equipment in batch production. To formalize structural elements, an equipment model is used in accordance with the IEC 61512 (ISA-88) standard, which allows for a clear representation of the equipment hierarchy, as well as the construction of information models suitable for integration into modern control systems.

## 5. Results of investigating the decomposition of a CIP station

### 5. 1. Defining the criteria on the basis of which the objects of the equipment model hierarchy are identified

To use all the advantages of flexible use of resources, first of all, it is necessary to decompose the equipment into interconnected objects according to their functions and roles. The decomposition rules are quite well defined in IEC 61512 (ISA-88), which provide for a hierarchical structure of objects responsible for a specific group of equipment according to its role. That is, objects are identified not only by the criterion of the connectivity of elements but also by the role in the manufacture of products or process control. These criteria are also dictated by the possibility of performing technological and/or management functions performed by this group of equipment.

All parts of the IEC 61512 standard [11] are oriented towards batch production; therefore, it specifies requirements taking into account the reference to the Batch portion. However, given that the CIP station is a continuous type object, although it has a short operating time from start to stop, it is not a Batch. Therefore, the criteria from the IEC 61512 standard cannot be used in their pure form. First of all, it is worth highlighting the main differences that should be taken into account when decomposing a CIP station:

1) according to the standard, all actions on a batch of substance (Batch) are carried out simultaneously, i.e., in one Unit, in a CIP station the technology involves the passage of CIP solution through a certain equipment, i.e., technological processes occur in a stream;

2) a CIP station does not produce a product in the sense as it is provided for in the standard, instead of a product it is worth understanding a "service", i.e., a specific cleaning of a specific equipment;

3) the objects of cleaning are other equipment that can perform its role in controlling the technological processes of product preparation. From the point of view of the standard, this should be an adjacent parallel system in a single hierarchy. However, in this case, the production role of the equipment being washed does not matter, so in different models they will have different purposes.

In the IEC 61512 standard [11] for the implementation of control functions, it is assumed that the process cell is divided into technological units, technological equipment modules, and control modules.

Decomposition of the physical model of technological equipment is often iterative. On the one hand, having experience with similar approaches, the list of typical lower-level objects is constant, so it can be "transferred" between different objects. For example, actuators are typical representatives of control modules, regardless of the type of object. However, at higher levels, the decomposition process is often not obvious and takes place in several iterations in different directions: top-down, bottom-up in the hierarchy, and even horizontally.

Having a list of unambiguous objects, for example, actuators, the decomposition process can be started from the top down. First, it is necessary to determine the boundaries of the process cell, then to determine all the process nodes within it. The next step is to determine the equipment modules for each process node and process cell. And, finally, the control modules for each process equipment module, process node, and process cell are determined. At each step, it is possible to return to the previous ones.

According to IEC 61512 [11], a process cell is a logically grouped process equipment that is necessary for the production of one or more batches. Taking into account assumption 1, this definition can be formulated as follows: a process cell is a logically grouped process equipment that is necessary for cleaning one or more routes according to a specified scenario. The existence of a process cell allows it to be used as a basis for production scheduling [12], as well as to devise general control strategies for it.

According to the above, the process cell must meet the following criteria:

– group all the process equipment required for cleaning;

– define the collective belonging of the cleaning equipment, i.e., the process cannot go beyond the boundaries of the process cells.

According to IEC 61512 [11], the process cell must contain at least one process unit – a set of equipment that can perform one or more basic operations of the process. The process unit operates relatively independently of other process units. However, it cannot process or contain more than one batch at any time. In other words, different parts of one process unit cannot simultaneously contain parts of different batches. It follows that defining the boundaries of a process unit is a key decision in the decomposition of the physical model of process equipment.

In accordance with the above and the assumptions related to CIP, the identification of a technological node is carried out according to the following key characteristics:

– at one point in time, the technological node must ensure the execution of the cleaning of one route according to one scenario;

– the technological node can function independently of other technological nodes;

– accommodates (coordinates the work of) modules of technological equipment and control modules, on a permanent basis or temporarily to perform cleaning tasks.

The lower levels of the model are the Equipment Module and the Control Module, which at first glance have similar functions. According to IEC 61512 [11, 13] the module of technological equipment (Equipment Module) is a group of equipment that can perform a limited number of small technological operations.

According to these and other requirements given in IEC 61512, the Equipment Module can perform technological operations. Therefore, the question of its difference from the Unit arises. It is possible to distinguish the key differences between them [11, 14], which are given in Table 1.

Table 1

Differences between an equipment module and a technological node

| Technological node | Technological equipment module |
|---|---|
| Centered around the main technological equipment | Centered around auxiliary technological equipment |
| Can perform several technological actions simultaneously | Can perform only one technological action at a time, as a rule, it is for this purpose that it is used |
| Can perform a different set and sequence of technological actions for different recipes | Regardless of the scenario, it always performs one technological action, only the parameters can be changed |
| Designed for independent operation (start and stop coordination is performed by the technological cell) | Coordinated by the technological node, or directly by the technological cell |
| Can interact with other technological nodes for coordination tasks | Receives commands from the upper level of the hierarchy (technological node or technological cell) and sends them its status |
| Can perform technological actions for only one batch at a time | The technological action being performed can concern several batches |

At the same time, according to IEC 61512, the execution of technological actions is not mandatory for an Equipment Module, but to avoid confusion and simplify decomposition, it is further considered that an Equipment Module always performs a technological action.

A technological equipment module always includes control modules or may contain other equipment modules. In any case, a technological equipment module cannot directly affect the equipment. Since an equipment module can be a shared resource, it can be designed and configured to work on more than one batch at a time. Some examples of common technological equipment modules are a concentrated cleaning solution supply pump, a pressure regulator in a pipeline, etc. A technological equipment module is the lowest element in the physical model hierarchy that is capable of performing technological actions. Equipment modules cannot produce a batch on their own; they are used by technological nodes to perform a specific task.

Accordingly, the Equipment Module must meet the following criteria:

– performs at least one technological action of the wash or preparation for the wash, as a rule, it is for it that it serves;

– can perform only one technological action at a time;

– cannot perform a sequence of technological actions;

– can be coordinated by a technological node or technological cell;

– can perform an action for several washes simultaneously.

The Control Module is the lowest level in the hierarchy of the physical model, which performs the main function of controlling technological equipment, usually a set of sensors and actuators. The main purpose of the control module is to perform basic equipment control functions, without direct connection to the technology. That is, the control module does not perform the technological action itself but influences its course or provides control over its execution. Typical representatives of the control module are sensors, starters, actuators, converters, and other instrumentation. A good criterion for defining a control module is its representation on the P&ID diagram as control and management tools and functions. For convenience, control modules can include other control modules. Control modules cannot perform procedural control, but they are used by other elements of the hierarchy to perform procedural control when specific actions need to be performed. Since a control module can be a shared resource, it can be used and configured to work on one or more batches simultaneously.

With this in mind, Table 2 highlights the differences between process equipment modules and control modules.

Table 2

Differences between a hardware module and a control module

| Technological equipment modules | Control modules |
|---|---|
| Ensures the execution of a certain technological action from start to finish | Performs only basic equipment control, which is not sufficient to perform the entire technological action |
| Influences the state of technological equipment only through the control modules that are part of it | Directly affects the technological equipment |

As a rule, control modules receive basic control commands and generate their status in which they reflect the state of the equipment, and various kinds of alarms. Given this, it follows that only one control module should control one device, in order to avoid situations in which commands that contradict each other are generated. This problem can be solved by coordinating the operation of common technological equipment by the upper levels of the physical model hierarchy [15].

Accordingly, the Control Module must meet the following criteria:

– performs only the functions of basic equipment control, does not implement technological action;

– implements the function of equipment control and management.

The IEC 61512 standard considers batch production process management from two different points of view: technological process and equipment. The representation of technological equipment is made through the eyes of a mechanical, electrical, and instrumentation engineer, and ultimately becomes a physical model from the point of view of IEC 61512. The representation of the technological process is made through the eyes of a technologist and describes the technology and ultimately is a model of the technological process. The ultimate goal of IEC 61512 is to make it possible to implement various technological processes on various available equipment.

The technological process at the early stages of the product life cycle is not tied to a specific equipment. Therefore, the general criteria for equipment decomposition, which are given above, must be supplemented by possible technological actions that it can implement according to the technological process models.

For this purpose, the technology is implemented as a set of procedures that can be performed on the equipment in one way or another (Fig. 1). Each procedure ultimately has an implementation in the equipment control, which, through control modules, implements control actions and provides control. The implementation of technology through control and the interconnection of procedures is called procedural control. The relationship between the technological process model and the physical model is illustrated in Fig. 1.

Unlike the technological process model, which has a certain abstraction, the procedural control model is related to a specific technological equipment or certain of its elements, since its components refer to the implementation in the equipment. Thus, the technological cell procedure describes the strategy for carrying out the main processing actions during the technological process. Or in other words, a process cell procedure is a sequence of process node procedures required in the case of CIP to clean a specific group of equipment on a route. This is the highest level in the hierarchy of the procedural control model, and it organizes the control of process equipment within the process cell [16].

As shown in Fig. 1 [11], the procedure can be further divided and distinguished into process node procedures, operations, and stages. The scope of the procedure is the process cell.

A process node procedure is an ordered set of operations that are performed until their completion on a single process node. That is, a process node procedure is a continuous production sequence that acts on one and only one process node. At any given time, only one process node procedure can be active. Several such procedures can be performed simultaneously as part of one process cell procedure if they are performed in different process nodes.

An operation is an ordered set of steps that are performed within a single process node. The boundaries of operations, as part of a process node procedure, must be defined as a logically completed part of the technological process, the execution of which can be safely completed. That is, the definition of the boundaries of operations must be made so that they define only a certain change in the course of the technological process. As with process node procedures, the standard provides that only one operation can be active on a given process node at a time.

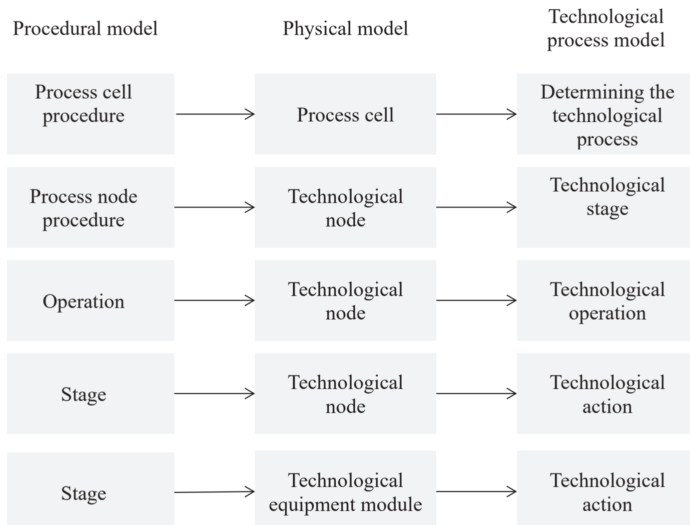


Fig. 1. Relationship between physical model and process model according to IEC 61512 [11]

**5. 2. Construction of a CIP station equipment model, in accordance with the principles of the IEC 61512 standard, with the identification of the basic components**

The CIP station at a dairy enterprise is a technological cell (Fig. 2) as it is responsible for the functions of cleaning technological equipment and independently produces batches of products – a cleaning solution of certain characteristics.

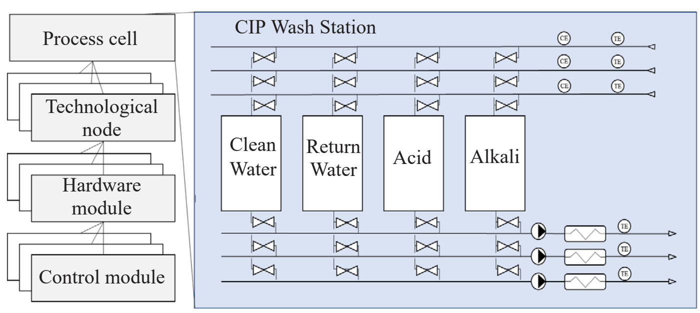


Fig. 2. Technological cell of the CIP station

The CIP station is a technological cell because it meets the following criteria:

– produces a batch and delivers it to the destination point, which is a cleaning solution of certain characteristics (temperature and concentration);

– groups all the technological equipment necessary for the production of the batch: sensors and actuators, tanks for storing cleaning solutions, pumps for supplying cleaning solutions, heaters, etc.;

– the CIP station is an independent unit in calendar planning, and the upper levels, having information about its productivity, can use it to build production schedules;

– the technological cell coordinates the equipment within its limits, as well as coordinates the use of common equipment – pumps for supplying concentrated cleaning solutions.

In the case of the CIP cleaning technological cell, three technological nodes are identified and defined – which are independent circuits of the CIP cleaning. They are marked in Fig. 3: 1 – cleaning circuit 1, 2 – cleaning circuit 2 and 3 – cleaning circuit 3. Each CIP cleaning circuit is used for cleaning a specific technological equipment, and their tasks are to prepare a cleaning solution of certain characteristics, supply it to the cleaning location, and pump it back.

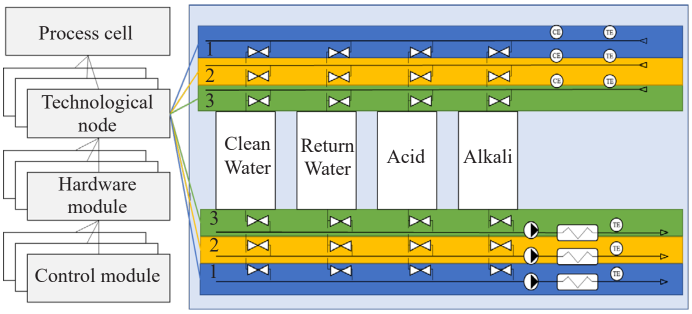


Fig. 3. Technological units of the CIP station

2. Heat exchangers for heating the supply of cleaning solutions for each cleaning circuit (3, 4, and 5 in Fig. 4, respectively).

This equipment module includes the following technological and control equipment, which function together: a solution supply temperature sensor, a steam supply valve to the heat exchanger, and a PID controller. Modules of this type perform the hardware stage of heating the cleaning solution to a certain temperature. They are a resource of exclusive use and are used only by the cleaning circuit of which they are a part.

All other sensors and actuators are control modules and are directly subordinate to the technological unit of the CIP cleaning circuit.

In accordance with the described criteria, the control modules for the technological equipment of the CIP station were identified, and their affiliation with higher-level hierarchy objects was determined (Fig. 5).

The CIP circuits are technological nodes because they meet the following criteria:

– when executing a scenario, they perform the scenario procedure that meets the requirements for a specific wash;

– all circuits operate independently of each other, and their coordination is carried out by a technological cell. An example of coordination can be the non-simultaneous supply of the same type of cleaning solution to different circuits, taking into account their limited number;

– controls all equipment and control modules used in cleaning by a specific circuit;

– can launch several different procedures (for example, alkaline cleaning, acid cleaning, pumping, etc.) and different recipes with different sequences of procedures;

– at a specific moment in time, the CIP circuit can wash only certain equipment – that is, execute one scenario and produce one batch of products.

Tanks for storing cleaning solutions will not be technological units as they do not perform any processing functions of the technological process, except for storing cleaning solutions, and no scenario is provided for them. In the case of a CIP station, the following modules of technological equipment are distinguished (Fig. 4):

1. Concentrated detergent solution dispensers: acids and alkalis (1 and 2 in Fig. 4, respectively).

This technological equipment is categorized as an equipment module because it can independently perform only one hardware stage – the supply of a certain amount of concentrated detergent solutions. In addition, all its activity is concentrated around a small part of the equipment, namely the dispenser pump. This technological equipment module is a resource for collective use and can be used by any technological unit (cleaning circuit) during cleaning, or by the entire technological cell in the process of preparing a cleaning solution. In addition, these technological equipment modules can accumulate and generate reporting information on the use of concentrated solutions in general, and during the execution of a specific master scenario for cleaning.

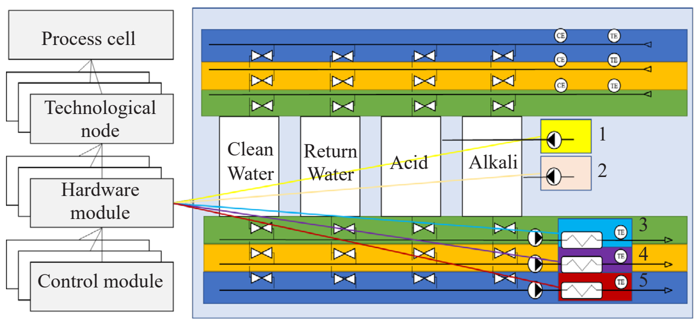


Fig. 4. Modules of technological equipment in the CIP station

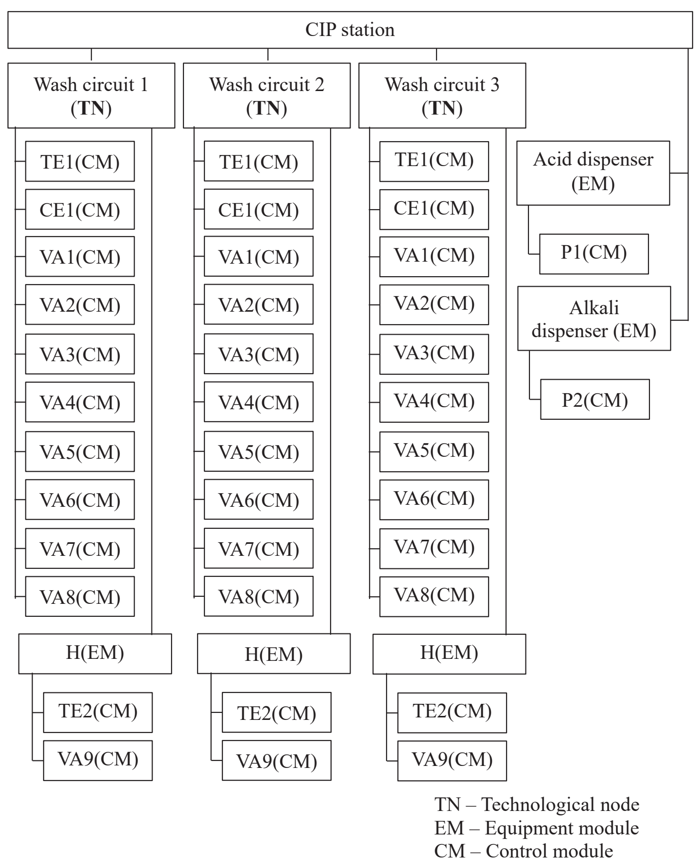


Fig. 5. Physical model of the CIP station

The following groups of control modules are identified:

1. Directly subordinate to the technological unit (identical for all technological units – the CIP circuit of the wash):
– cleaning solution return temperature sensor (TE1 in Fig. 5);
– cleaning solution return concentration sensor (CE1 in Fig. 5);
– acid supply valve (VA1 in Fig. 5);
– acid return valve (VA2 in Fig. 5);
– alkali supply valve (VA3 in Fig. 5);
– alkali return valve (VA4 in Fig. 5);
– returned water supply valve (VA5 in Fig. 5);
– returned water return valve (VA6 in Fig. 5);
– clean water supply valve (VA7 in Fig. 5);
– return valve to the sewer (VA8 in Fig. 5).

2. The heater (identical for all CIP station circuits) is subordinate to the technological equipment module (H in Fig. 5):
– steam supply valve to the heat exchanger (VA9 in Fig. 5);
– cleaning solution supply temperature sensor (TE2 in Fig. 5).

3. The concentrated alkali dispenser is subordinate to the technological equipment module:
– concentrated alkali dispenser pump (P2 in Fig. 5).

4. The concentrated acid dispenser is subordinate to the technological equipment module:
– concentrated acid dispenser pump (P1 in Fig. 5).

**5. 3. Construction of a model of the technological process of the CIP station with division into main elements**

A technological stage describes the main processing function, which usually leads to a planned sequence of chemical and physical changes in the properties of the material being processed during the technological process. Each technological stage consists of an ordered set of one or more technological operations. Technological operations are the main activity during the technological process. Technological stages operate independently of each other. They can be further decomposed into ordered sets of technological operations and technological actions.

The identification of technological stages depends on the requirements for the technological process and is carried out individually in each case. The main criterion in their definition is that technological stages are independent parts of the technological process. The identification of technological stages involves determining the sequence of conversion of raw materials into a product, this is usually done by technologists [17].

In the process of CIP cleaning, the following technological stages can be identified:
– cleaning with recycled water;
– cleaning with acid;
– cleaning with alkali;
– cleaning with clean water.

A technological operation is the main activity of the technological process. A technological operation leads to chemical and physical changes in the properties of the material being processed. Each operation can be further divided into an ordered set of one or more technological actions.

Technological operations are completed logical parts of a technological stage. The identification of technological operations serves for a more detailed description of the technological process.

In the process of CIP cleaning, the following technological operations can be identified:
– technological operation "Supply of returned water" (technological stage "Cleaning with returned water");
– technological operation "Supply of acid" (technological stage "Cleaning with acid");
– technological operation "Cleaning after acid" (technological stage "Cleaning with acid");
– technological operation "Supply of alkali" (technological stage "Cleaning with alkali");
– technological operation "Supply of pure water" (technological stage "Cleaning with pure water").

Technological operations consist of an ordered set of one or more technological actions. They describe several minor processing operations that are combined to create an operation.

In accordance with the above, it is possible to build a model of the technological process of the CIP station (Fig. 6), which includes all levels of the technological process model in accordance with the IEC 61512 standard.

In the future, this model can be used to build a procedural model. As noted, the technological process model does not describe the requirements for specific technological equipment and can be implemented at any enterprise. Based on this model, a general scenario is formulated that generally describes the process of product design.

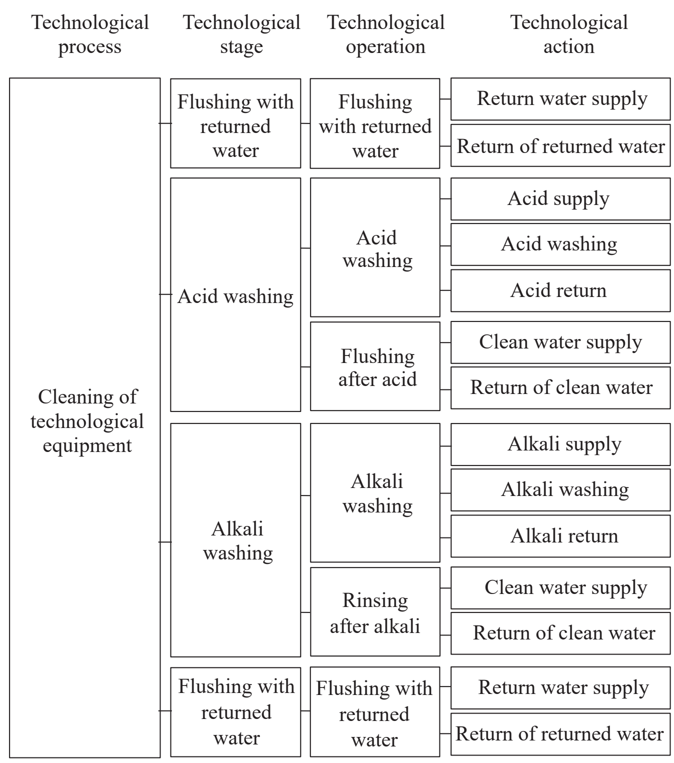


Fig. 6. Model of the technological process of a CIP station

**5. 4. Compiling recommendations for implementing object-oriented control at CIP stations**

The results of the decomposition allow us to offer a number of practical recommendations for the implementation of object-oriented control over CIP stations:

1. Using the IEC 61512 standard as a basic methodology. It is necessary to formalize the CIP station as a technological cell with a clear division into technological nodes, equipment modules, and control modules. This forms a basis for unifying the description of equipment, increases transparency, and facilitates integration into general production control systems.

2. Construction of object libraries. Based on the selected equipment and control modules, it is advisable to build libraries of software objects (pump, valve, heat exchanger, dispenser, etc.),

which can be reused in various automation projects. This reduces development costs, increases unification, and facilitates system scaling.

3. Integration of procedural control. Since the equipment cleaning processes are batch-based, it is advisable to formalize them in the form of procedures of technological units and hardware stages, which are directly associated with the objects of the physical model. This increases flexibility in the formation of cleaning programs and ensures the adaptability of the system to changes in production requirements.

4. Ensuring coordination of resources for collective use. At CIP stations, there are equipment modules that can be used by several circuits (for example, concentrate dispensers). To avoid conflicts, it is necessary to implement mechanisms for centralized control over access to such resources at the technological cell level.

5. Use of AutomationML and OPC UA standards. For informational representation of objects at a CIP station, it is advisable to use modern engineering formats and communication standards that ensure compatibility between different levels of automation and facilitate integration with upper-level control systems (MES/ERP systems).

Before implementation in production, it is recommended to check the built models of a CIP station in simulation environments, which makes it possible to identify possible decomposition errors, optimize the sequence of procedures, and reduce risks at the stage of actual operation.

The recommendations received indicate that object-oriented control is an effective tool for increasing the productivity and flexibility of the CIP station. They provide a reduction in costs for the design and maintenance of automation systems, as well as form a basis for their integration into intelligent production complexes.

## 6. Results of investigating the decomposition of a CIP station: discussion

Our research results are attributed to the features of the applied approach. The identification of a CIP station as a technological cell (Fig. 2) provided a clear definition of its boundaries and functions. This allowed it to be brought into line with the requirements of IEC 61512 and to build a model that is easily integrated into production systems. Such a result is possible due to the systematic use of the principle and rules of decomposition when constructing a hierarchical model.

The formation of three independent technological nodes (Fig. 3) is explained by the fact that each CIP-cleaning circuit implements its own scenario procedures and can operate independently of each other. This provides autonomy and the possibility of parallel operation, which reflects the key advantage of the model. Compared to conventional solutions [1, 3], in which CIP stations are described only as a set of functional blocks without formal division into nodes, the proposed approach makes it possible to maintain flexibility and simplify scaling.

The separation of technological equipment modules (Fig. 4) and control modules (Fig. 5) was made possible by the detailing of the hardware stages and the IEC 61512 criteria. The advantage compared to existing approaches [4, 7] is that the CIP station model creates conditions for the reuse of modules in control libraries. Unlike general methods of modular PLC programming, this work takes into account the specifics of batch processes and introduces a clear link to cleaning procedures.

The resulting process model (Fig. 6) could become a basis for building a procedural model of the CIP process control. Such a model describes the logic of the process at the conceptual level, focusing on the sequence of actions, rather than on the hardware implementation. On its basis, a general scenario can be formed that reflects the algorithm for designing a product and coordinates the process procedures with the functionality of the equipment.

Thus, the results of our study directly close the methodological gap through the following:

– the complexity of control is eliminated by introducing a hierarchical structure (process cell > process node > equipment modules > control modules);

– low flexibility is overcome through the possibility of using procedural control elements;

– the lack of an object-oriented approach is solved by integrating IEC 61512 and procedural modeling.

The limitations of the study are that the construction of the equipment model and the process model was carried out on the example of one CIP station at a dairy enterprise. In practical application, results may vary depending on equipment configuration and technological requirements.

The disadvantage of our study is that it does not include experimental verification in real production but is based on documentation analysis. This limits the possibility of immediate implementation without additional testing.

Further studies may tackle the following tasks:

– construction of object libraries for SCADA/PLC systems with the possibility of automatic code generation;

– integration of CIP station models with upper-level control systems (MES, ERP);

– testing of decomposition on other types of technological objects (fermenters, pasteurization plants) to verify the universality of the approach.

Given this, it is possible to devise a holistic methodology for object-oriented control over production systems, suitable for widespread use in the food, pharmaceutical, and chemical industries.

## 7. Conclusions

1. As a result of investigating a CIP station and the structure of the technological process, decomposition criteria have been defined that take into account the functional autonomy of the nodes, the logical completeness of the procedures, and the possibility of reusing the equipment. The result is attributed to the structural application of the "top-down" principle and the use of hierarchical modeling provided for by the standard.

2. Based on the determined criteria, a hierarchical model of the CIP station equipment was built, in which the levels of the technological cell and three technological nodes corresponding to individual cleaning circuits were identified. A feature of the model is ensuring the independence of the nodes when sharing resources (dozers, tanks), which increases the flexibility of the CIP station. Compared to conventional approaches, in which the circuits are described by a set of algorithms, the proposed model simplifies the coordination of the actions of the control system. This result is explained by the implementation of the object-oriented principle of grouping control functions.

3. As a result of our study, a model of the CIP process was built, which describes the relationship between the technological stages, procedures, and equipment of the CIP station. The model has been constructed in accordance with the structure of the IEC 61512 standard and reflects the sequence of implementation of the technological process. Unlike known models, in which technological procedures are described only

algorithmically, the proposed model defines a clear hierarchy of procedural actions. Our result is attributed to the application of the principle of decomposition and a systems approach, which ensured the structure of the model and its versatility.

4. Recommendations have been compiled for the practical use of the decomposition results: the formation of libraries of software objects, integration with AutomationML and OPC UA, coordination of shared resources. A feature of these recommendations is the combination of the hardware and information structures of the CIP station, which distinguishes them from known technological descriptions. This is explained by the use of the provisions of IEC 61512 with modern automation technologies.

## Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

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## Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

## Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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