

System Analysis and Design of Flexible Plant of Ultra Pure Materials

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System analysis methodology for flexible production plant on various levels has been developed. The levels include workshop, department and flexible production of ultra pure materials. Main principles of flexible systems synthesis have been formulated. An example of the design of the department for flexible production of mineral ultra pure salts assortment is provided.

1. Methodology of System Analysis for the Flexible Industrial Production

The systems analysis of the structure of flexible retrofit of the main process plant unit - the shop - provides four hierarchical levels: nomenclature (I), manufacturing-technological (II), organizational-technological (III) and organizational-industrial (IV). Three aspects of flexibility correspond to that hierarchical structure: technological, structural and organizational (Fig. 1).

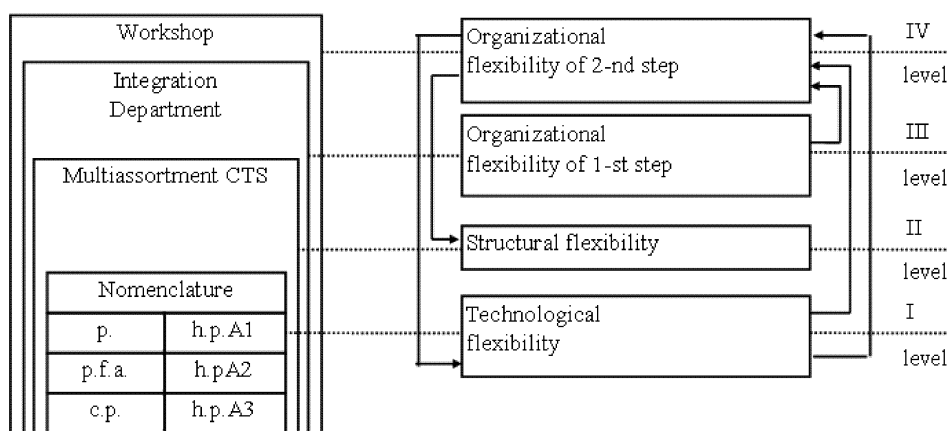


Fig. 1. Hierarchical workshop structure of a flexible production system

As a matter of convenience the following performances of levels are offered: nomenclature level, manufacturing-technological level, organizational-technological, organizational-industrial level.

Nomenclature level

Attribute: a product of one kind or one process stage.

Problems: expansion of a set (packet) of qualifications of one product;

Variation of power of a process stage. The operation of the given level is ensured by technological flexibility. It is defined by ability on the available equipment to carry out some process tasks in following ways:

- due to the flexible process methods of deriving of preset substances (under the nomenclature);
- at insignificant costs, to re-adjust the equipment (stopping for washing, re-piping and other operations).

Manufacturing-technological level.

Attribute: multi-assortment production.

Problems: optimal use of intermediates and common initial reagents;

Use of elements of flexibility to expand industrial groups according to the names;

Variation of capacity of all technological processes. The implementation of the given level is ensured by structural flexibility, which is characterized by an opportunity of modular extension of a system, and also properties of periodic operation units (multifunction use of the same units).

Organizational-technological level.

Attribute: integrated department.

Problem: optimisation of the set of equipment units;

Minimisation of a production cycle. The operation of the given level is ensured by organisational flexibility of 1st step, which enables maximum loading of the process equipment at the implementation of a production cycle. It can be implemented only when all integrated departments within the limits of shops are interconnected by both material and information flows.

Organizational-industrial level.

Attribute: shop as a complex cybernetic system.

Problems: stabilisation material and information flows between integrated departments;

Distribution of raw materials, power and labour. The operation of this level is ensured by organizational flexibility of 2nd step, which contains a set of problems of flexible calendar scheduling and control with the centralized distribution of operations.

As an example of technological flexibility we consider a process of isothermal crystallizing purification (salting-out) of lead nitrate of different purity grades (Kafarov et al., 1991). The given process is considered at reconstruction of operating production of lead nitrate of reactive grade. Due to perfecting a method of clearing and variation of stream structure the essential improvement of quality of a product and double increase of output is obtained on the same equipment (Bessarabov et al., 1987). Also the process is considered for development of new multi-assortment production of lead nitrate of three reactive purity grades and two grades of high purity.

2. Main Principles of Synthesis for the Flexible Ultra Pure Systems

By considering the structure of a workshop in terms of its retrofit there is a problem of design of a department with a new structure based not on individual processes, but by including multi-purpose clusters of processes, combined processes or flexible processes. Since individual processes of all departments which are included in the workshop, have common cycle of productions, it is reasonable to combine individual processes during the retrofit by the any of four ways:

- Combination of a cycle of raw material preparation on the basis of common physical-chemical processes implemented at handling (treatment) of initial ingredients (dissolution, filtering, subdivision, refinement, calcination etc.).
- Combination of work cycles on the basis of common chemical mechanisms of processes, uniformity of the equipment used.
- The architecture of joint packing centre of FP (final products) which consists of three operational - technological modules of packaging FP: in containers, in cardboard rolls, in sacks (craft, polyethylene etc.).
- Setting up a fully integrated cycle.

As a result of such synthesis, the department retrofitted structure can be of four types.

The architecture of common packing centre of FP, as well as integrated cycle of preparation of raw material, is a simpler technological and engineering problem compared to the problem of design of an integrated processing cycle. The reason for that is that at packing of FP and at preparation of raw material, the same unit operations are carried out and the identical process equipment will be utilised.

We will consider, for example, a packing in containers individual process. It includes the following technological components: a warehouse of empty containers, scales for monitoring filling the container, uploading system (pipe or other engineering system connecting a feed bin or the process unit to a neck of the container), auto- and electric forklift for warehousing packaged production. This set does not depend on a type of FP and conditions of packaging: the process of packing both in rolls and in sacks will be similar. The only difference is the container, and there is economy in technological operations.

The complexity of architecture of packing centre requires designing the process equipment the way that all process stages of packing of FP should space-wise converge in one territorial point, in which the packing centre is set up.

The architecture of an integrated cycle for preparation of raw materials in equipment units should be process modules for implementation of defined classes of physico-chemical processes. The complexity of architecture of a given cycle is determined by the sequence of process operations. It is necessary to provide washing of the process equipment after it has been used. It is impossible to immediately process another substance.

The architecture of an integrated process cycle is the most complex problem, as there are issues of overlapping of the products not only on the basis of similarity of their physical and chemical properties, method of production, but also on the basis of an attributing them to a defined class of substances. In production of high purity

substances, depending on a degree of high purity of a main product, two basic classes of substances are distinguished: chemical reagents and highly pure substances (Ryabenko et al., 2003).

Before starting retrofit it is necessary to clarify:

- Chemical composition of a main product, its class and composition admixtures;
- Method of manufacturing of a product and implementation of technological process;
- Types of the equipment used.

We will consider the architecture of integrated department at an example of inorganic salts production, i.e. from all the range, produced by the workshop, we will select mineral acids salts, and from them, in turn, the hydrogen nitrate salt. We define one of the classes as the main product. Chemical reagents and high purity substances in the following nomenclature composition can be produced: chemical reagents of qualifications "p.", "p.f.a.", and "c.p." and high purity substances of the marks A1, A2, A3 etc. Thus, the output production has identical chemical composition of the common formula MAc (Ac-acid rest), but differs in the range. It means that assortment-wise the target substances are integrated in two packets: a packet of reactive grade quality and packet "of high purity" grade.

In a similar way we consider the other salts available in production of hydrogen nitrate. Further we combine them in groups to the following technological attributes of production:

- Method of production of the main product: synthesis of the main product, crystallizing clearing of lower qualification substance, synthesis with consequent crystallizing clearing;
- Process operations: dissolution, filtering, evaporation, crystallization and drying FP etc;
- Equipment: filtering equipment of one type, immersion (drum-type) crystallizers etc.

3. Design of the Flexible Department of Mineral Ultra Pure Salts

The structure of integrated department for production of the groups of mineral salts as a result of retrofit is shown in a Fig. 2. One of the important problems is the alignment of the department production architecture in line with the flexible production principles. An effectiveness criterion is recommended that relates cost increment of flexible production architecture to an increment of consumer value of assortment of production. This approach makes sense, when it comes to development of new production for new assortment. In case of retrofit of existing production, the basic (the first) index is the comparative estimation of the cost of products manufactured before the retrofit.

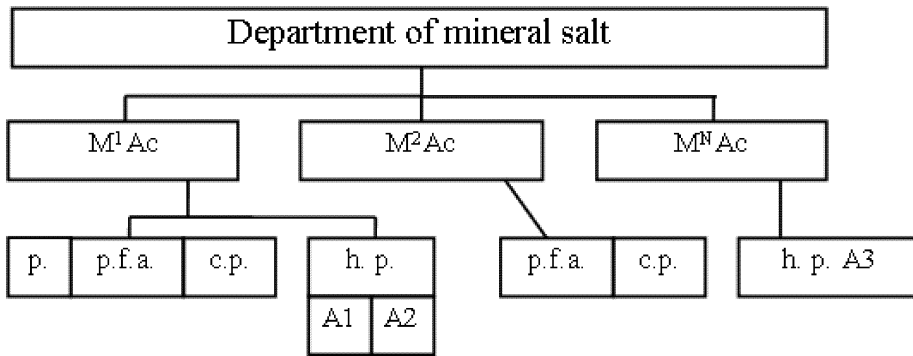


Fig. 2. Organizational and industrial structure of an integrated department of mineral acids salts production

The second estimated parameter can be the coefficient of process flexibility (CPF), which characterises the number of the combined products and the number of processes implemented at the same equipment as process modules within the limits of the process retrofitted.

Cost includes raw materials, capital costs, cost of fuel and energy and labour costs which can be easily calculated. When retrofitting of the production line by introduction of an integrated department, it is necessary to take account of the jobs. When flexible production is implemented, labour redundancy may occur. The cost and CPF are coupled among themselves as follows: the more value CPF, the lower product cost manufactured by retrofitted CTS is, provided that the retrofit does not require capital investments, or they are insignificant. The reason for that is that the increase of output of production at the same investment costs results in reduction of overheads.

Hence, in case of retrofitted process the cost of products is reduced with the expansion of assortment. It is necessary to make the retrofit to achieve a fully-integrated department, i.e. creation of FPS on operating production.

To obtain a quantitative estimation of retrofit it is necessary to conduct the analysis of operating production with the purpose of selection of groups of processes, for which organization on the principles of flexible production systems is beneficial (Ryabenko et al., 1996; Lainez J.M., 2009; Puigjaner L. and Heyen G., 2007).

The first stage of this analysis is the decomposition of products manufactured on the basis of the hierarchical approach to three basic attributes: technological similarity, chemical similarity and classes of main products.

Each of the attributes above has the levels of gradation. So, the technological similarity is subdivided into similarity of methods of preparation of raw materials (dissolution, filtering, subdivision etc.), methods of production (type of transformation of raw materials into a main product, uniformity of technological operations and equipment used), and methods of packing of final production.

The chemical similarity is determined primarily by attribution to the same class (acid, salt, ether etc.). Inside the class, the sublevels based on physical-chemical properties of

junctions of the given class are selected. For example, the salts will be categorised depending on the character of the acid rest (nitrates, sulphates, phosphates etc.).

Main products can be divided in chemical reagents and high pure substances, inside which distinguish grades and marks of products.

The second analysis stage is the aggregation of processes based on similarity. Thus the different cycle of productions can be combined: preparation of raw materials, manufacturing of products (target substances) and packing the final product.

Each cycle will be organized by separate combined schemes, where the products are made with reference to their physical and chemical attributes chosen above.

4. Conclusions

Based on the system analysis methods, key flexibility levels in production, department and shop categories were singled out for the design of high-purity materials production plant. Main purposes and tasks have been formulated for each level. It is shown, that application of flexible systems allows to increase assortment and capacity of production on the same size plant footprint and the same equipment.

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