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Information CALS-model of Granulation Processes of Multicomponent Materials

Dmitriy Makarenkov[a], Vasiliy Retivov[a], Vjacheslav Nazarov[a], Georgiy Priorov[a,*], Arkadiy Bessarabov[b]

[a] National Research Centre "Kurchatov Institute" – IREA, Moscow, Russia
[b] R&D Centre "Fine Chemicals", Moscow, Russia
priorov@irea.org.ru

Energy-saving processes for granulating multicomponent materials are widely used in industry. To develop these processes, an information CALS-model was created at 6 levels of the hierarchy. At the top level, a grouping is carried out according to 8 types of medium for granulated materials. At the 2nd level of the hierarchy, for each type of medium, 11 classes of granulated products are considered and assigned. At the 3rd level of the hierarchy, specific target products related to the corresponding types of media and classes of granulated materials are considered. At the 4th level, the system architecture includes the main methods for obtaining granular compositions, for each of which, at the 5th level, technological equipment - granulators is considered. At the last 6-th level of the hierarchy, the main indicators of product quality are analyzed. The carried-out systematization allowed for the first time to develop a multifunctional information system that effectively solves a set of tasks: the operational search for a multicomponent product, taking into account the type of medium and the class of granulated materials; analysis of the main quality indicators with subsequent selection of the optimal granulation method; selection of advanced equipment for each considered granulation method. The developed CALS-system improves the quality of scientific research by improving access to the necessary unified information.

1. Introduction

Currently, energy-saving processes for granulating multicomponent materials (MCM) are widely used in various industries: chemical, petrochemical, pharmaceutical and metallurgical. In agriculture, the use of granulation of raw materials makes it possible to obtain granulated fertilizers and animal feed. Today, the production of fuel pellets from waste wood and the agricultural sector (husk, straw, etc.) is very common. Granulation processes are carried out by compacting on rolls with a smooth surface, rolling on rotary granulators with an annular or flat matrix, pelletizing on disc and high-speed turboblade granulators (Siuda et al., 2021). The choice of a rational granulation method is carried out taking into account structural, deformation and rheological characteristics (Makarenkov, 2017).

There are many publications in the literature on chemistry and technology (Thapa, 2019), process development (Ostroha et al., 2021) and the creation of apparatuses (Makarenkov et al., 2014), for granulation of multicomponent materials (Siuda et al., 2021). However, at present, there are practically no works on the systematization of these studies and the creation of information and analytical systems. Research in this direction is the goal of our work.

Based on the methods of system analysis, for the first time the development of an automated system of scientific research (ASRS) of the processes of granulation of multicomponent materials was carried out. ASRS significantly improves the quality and efficiency of employees. The work was carried out on the basis of information CALS-technology (Continuous Acquisition and Life cycle Support). The CALS concept is based on a set of typical information models, correct interpretation of information and unification of access to it. The main thing that makes up the CALS concept and distinguishes it from others is invariant concepts that are fully or partially implemented throughout the product life cycle (Saaksvuori, 2010).

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The use of CALS in enterprises will increase the productivity of employees; minimize material and time costs and improve the overall quality of work (Pogosyan at al., 2017). This is ensured by: facilitating access to the necessary information; reorganization of activities (while maintaining the goals set); computerization of the workspace; correction of relationships between partner enterprises. The reorganization of activities within the framework of CALS will increase labor productivity, reduce time and material costs (Sizov et al., 2018).

2. Classification of granulated materials

To create ASRS, a hierarchical information model was developed (Figure 1). At the upper level, a grouping is carried out according to 8 types of medium for granulated materials: ideally free-flowing, free-flowing, elastic, viscoelastic, elastic-viscous relaxing, elastic-plastic, elastic-hardening, visco-plastic.

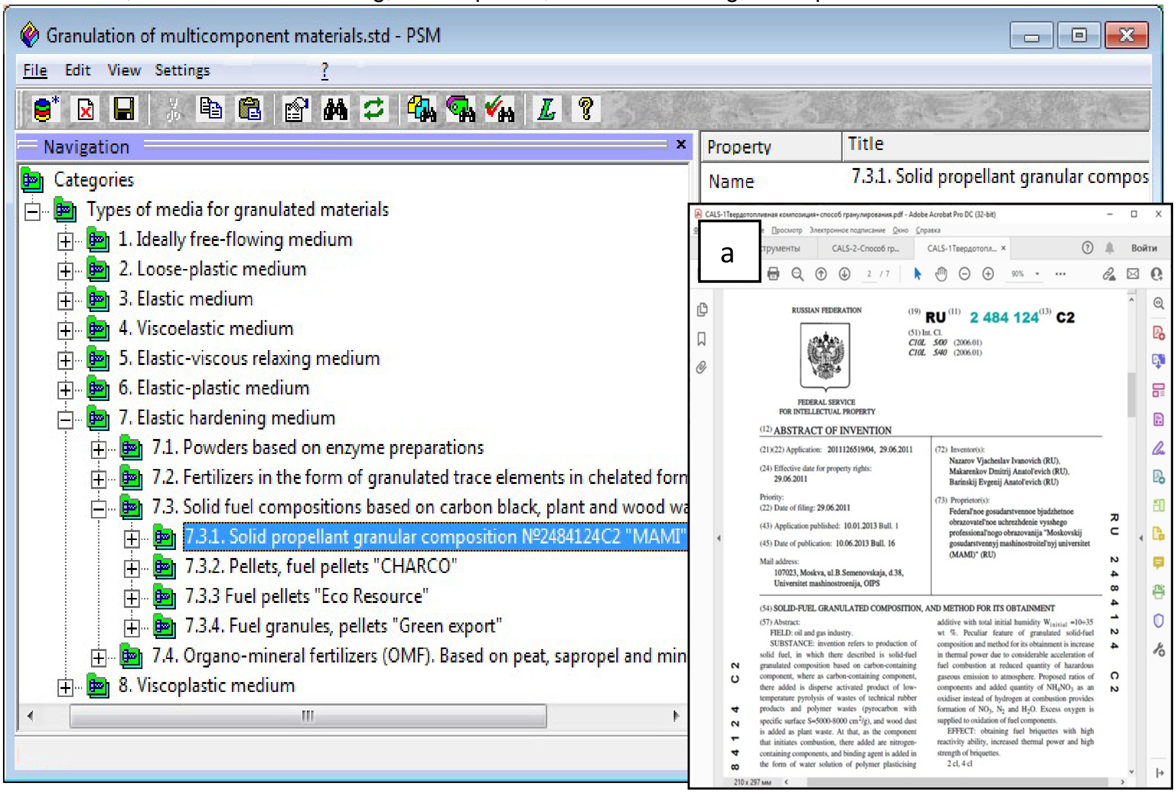

Figure 1: Screen form of the ASRS CALS project: Elastic solidifying medium - Solid fuel compositions - Composition No. 2484124 (a - Patent No. 2484124 "Granular solid fuel composition and method for its production")

At the second level of the hierarchy, for each type of medium, 11 classes of granulated products are considered and put in correspondence: glass-forming and enamel mixtures; silica porous materials; powders from pulverized fractions of clay masses; metal powders; powders based on enzyme preparations; solid fuel compositions; mixtures of paper-polymer masses; compound feed with additives of food industry waste; fillers based on ash, slag and porous waste; mineral fertilizers, complex NPK fertilizers (nitrogen-phosphorus-potassium); fertilizers in the form of granulated trace elements; organic fertilizers (Ostroha et ai., 2021).

Each class of products at the third level of the hierarchy is characterized by the range of materials considered (entered into information bases). In the CALS project (Figure 1), 3 elements of the 3-rd level were identified for an elastically hardening medium: powders based on enzyme preparations, fertilizers in the form of granular microelements in a chelate form on a mineral carrier, and solid fuel compositions based on carbon black, plant and wood waste (Nazarov et al., 2018). For solid fuel compositions, several types of products from different enterprises are included in the CALS project, including the developed and patented solid fuel composition No. 2484124 (Nazarov et al., 2013). This composition relates to the production of solid fuels in the form of briquettes, granules, compacts and can be used instead of natural fuel in everyday life, in boiler houses for domestic purposes, in industry and in car furnaces (Nazarov et al., 2018).

In the production of a solid fuel granular composition, nitrogen-containing components are introduced as a combustion initiating component, and the binder is introduced in the form of an aqueous solution of a polymer plasticizing additive with a total initial moisture content of 10–35 % wt. (Nazarov et al., 2013). A feature of this granulated solid fuel composition and the method of its production is an increase in thermal power due to a significant acceleration of fuel combustion with a reduced amount of harmful gas emissions into the atmosphere. The technical result is the production of fuel briquettes with high reactivity, increased thermal power, high briquette strength (Lin et al., 2021).

3. Classification of granulation methods and equipment

At the 4th level of the hierarchy of the information model of the CALS project (Figure 2), various methods for obtaining granular compositions are described. So, for one of the mixtures of paper-polymer masses with additives of vegetable and other types of waste (subcategory 5.2.2 "granulated IREA composition"), 3 granulation methods are included in the CQM system: compaction by rolling through a die, compaction on roller presses and pelletizing on plate granulator.

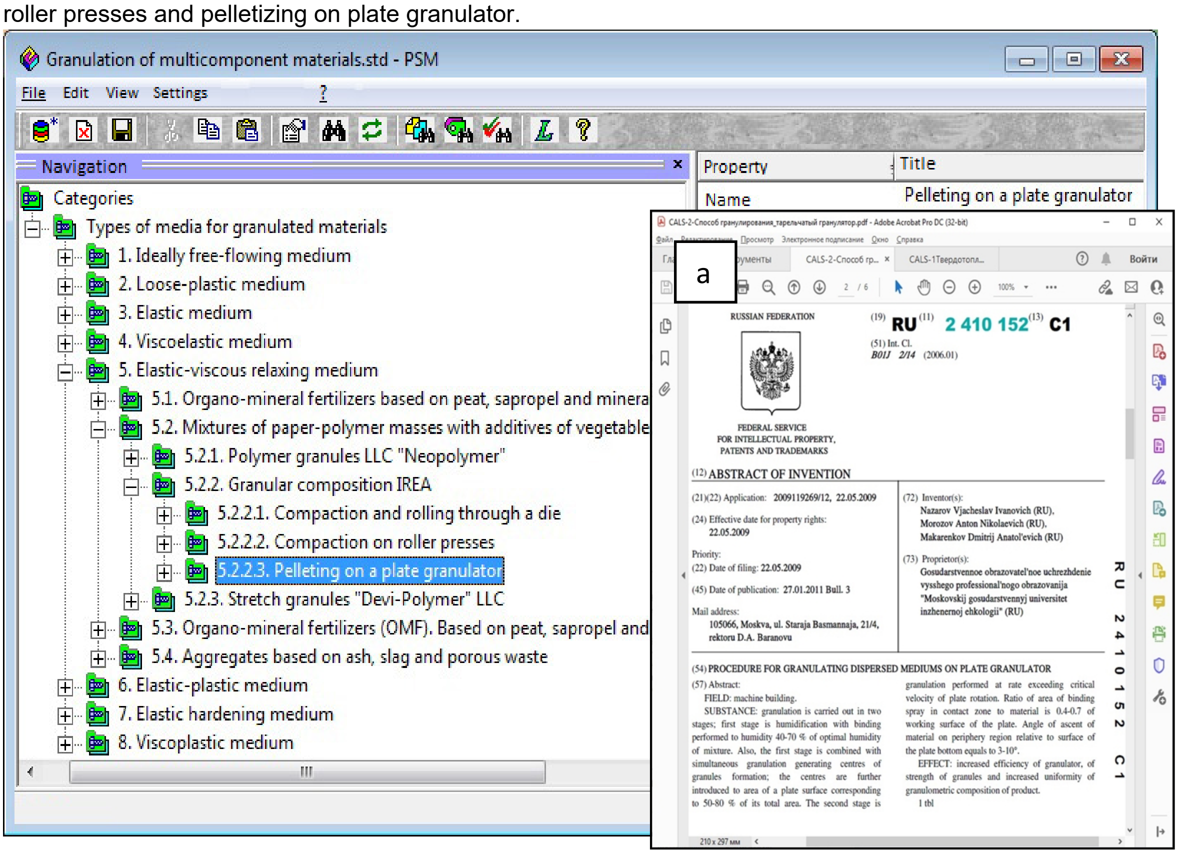

Figure 2: ASRS CALS-project: Elastic-viscous medium - Paper-polymer mixtures - IREA composition - Pelleting on a plate granulator (a - Patent No. 2410152 "Method of granulating dispersed media on a plate granulator")

The pelletizing method on a plate granulator can be used to obtain mineral fertilizers, animal feed, and biologically active preparations (Putranto et al., 2015). The plate granulator is an inclined plate in the form of a disc with sides with a flat bottom, driven by an electromechanical drive. The tray is closed with a lid, on which are mounted: branch pipes with nozzles for the introduction of a binder, devices for cleaning the bottom and sides of the tray from sticking product, technological hatches and fittings. The tilt angle of the plate can be changed by rotating the frame using a jack with an individual drive (Nazarov et al., 2011).

Granulation is carried out in two stages. The first stage is the stage of wetting with a binder. It is carried out to a moisture content of 40-70 % of the optimum moisture content of the mixture. In this case, the first stage is carried out in a pre-granulator (an apparatus with blades). As a result, centers of granulation are obtained, then in the second stage they are introduced onto the surface area of the plate, which is 50-80 % of its total surface. At this stage, the granulation is carried out at a speed exceeding the critical rotation speed of the plate. The ratio of the area of the spray jet of the binder in the zone of contact with the material is 0.4-0.7 of the working surface of the plate. The angle of elevation of the material in the peripheral region relative to the bottom surface of the plate is 3–10° (Nazarov et al., 2011).

When an apparatus for the formation of embryos (turbo-bladed granulator-mixer) is included in the technological scheme for the production of spherical granules, the productivity of the plate granulator increases by 2–2.5 times and it becomes possible to control the size of the granules. The process becomes more stable and manageable. Disc granulators can be supplied complete with turbo-blade granulators-mixers (pre-granulators), hoppers for bulk products, dosing systems for liquid and powder components, which allows for a complete supply of equipment in the form of a plant or a production line (Nazarov et al., 2011).
To obtain a solid fuel composition by pressing, 3 corresponding types of equipment are included in the CALS project (Figure 3): a PGZH-1.5M press granulator, a press granulator with a flat matrix (development of the National Research Center "Kurchatov Institute" - IREA, patent No. 2527998) and a press - flat matrix granulator GPM-400.

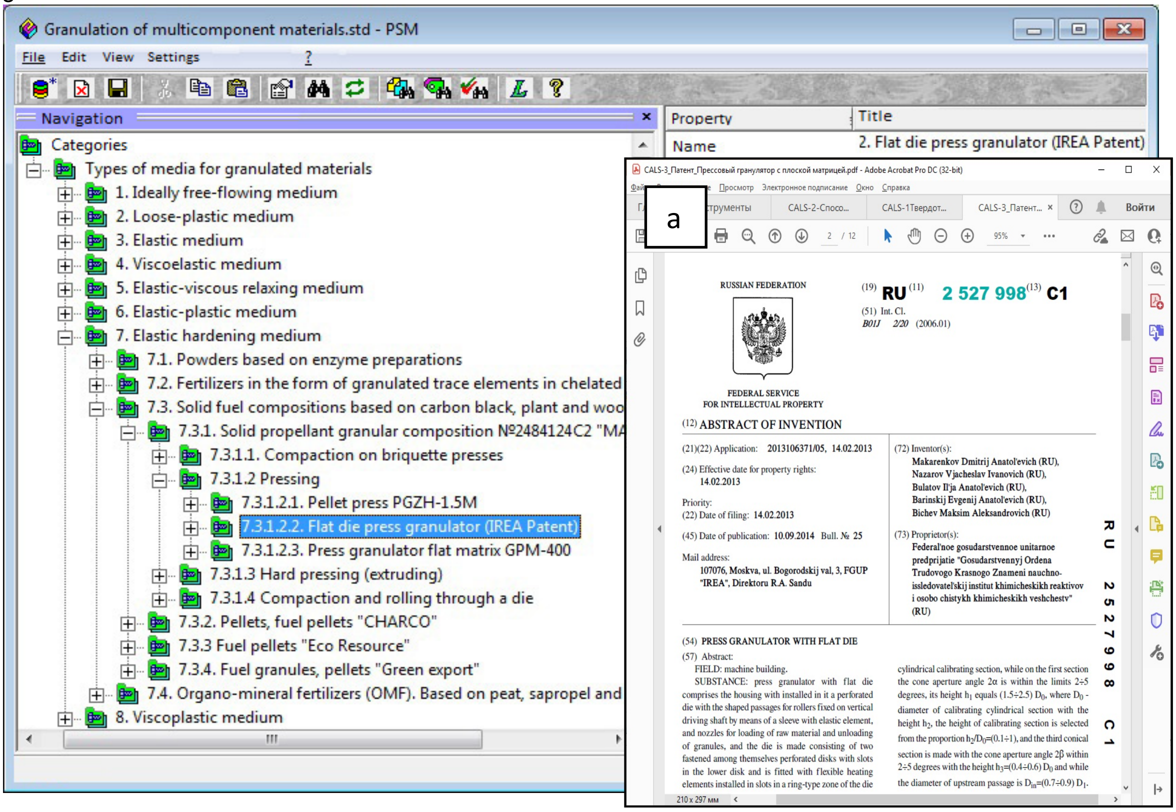

Figure 3: ASRS CALS project: Elastic hardening medium - Solid fuel compositions - Composition No. 24841240 - Pressing - Flat die press granulator (a - Patent No. 2527998 "Flat die press granulator")

The press granulator developed at IREA belongs to the type of devices for the preparation of granulated products and is designed to increase the strength and density of granulated material by reducing the labor intensity and cost of preparation (Makarenkov et al., 2014). This granulator with a flat matrix contains: a body with a perforated matrix installed in it with profiled channels; rolling rollers mounted on a vertical drive shaft by means of a sleeve with an elastic element; nozzles for loading raw materials and unloading granules. The matrix is made detachable from two perforated disks fastened together with grooves in the lower disk. It is equipped with flexible heating elements installed in grooves in the annular zone of the matrix. In this case, in the upper disk of the matrix, the profiled channels are made cylindrical, and in the lower one, the channel is made in the form of two conical and one cylindrical calibrating section.
To obtain a granular mixture based on paper-polymer masses by compacting on roller presses, 3 corresponding types of equipment are included in the CALS project (Figure 4): ARP-1 roller press, YKBM-360 brand roller press and PBV-19MP roller press.
High-pressure roller briquette presses (RBP) are designed to produce briquettes from various powdered raw materials: coal fines and coal dust, lime powder, soda ash, various salts, sodium carbonate, fluorite powder, slag after aluminum smelting, iron powder, converter dust, powder ferrosilicon, chromium powder, magnesium powder, refractory material powder and other raw materials. RBP is successfully used to produce fuel briquettes from various organic raw materials, including charcoal.

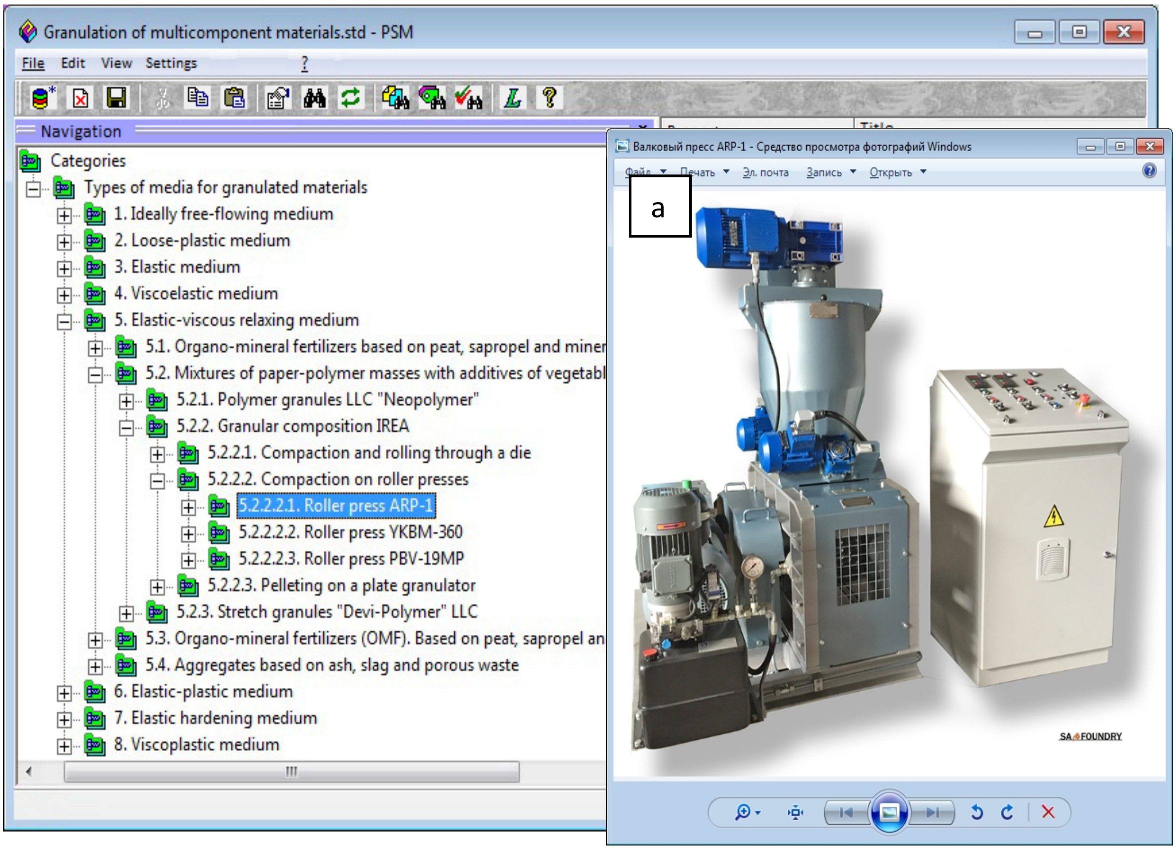

Figure 4: ASRS CALS project: Elastic-viscous medium - Paper-polymer mass - IREA composition - Compaction on roller presses - ARP-1 roller press (a - ARP-1 roller press)

The resulting briquettes are highly durable, easy to transport and provide efficient processing and use of raw materials. The briquettes produced by high pressure dry briquetting can come in various shapes, such as oval, egg, pillow, square, etc., according to customers' requirements. Dry granulation equipment makes it possible to compact powder particles of various raw materials into granules of a certain size. In dry granulation, the powder mixture is compacted without a binder by applying significant force to the powder (Diaz, 2018).

4. Classification of quality indicators

At the sixth level of the hierarchy, for all three stages of granulation (preparation, active loading, elastic aftereffect), 13 quality indicators are considered: plastic strength, flowability, formability number, internal friction coefficient, external friction coefficient, adhesion coefficient, coefficient of volumetric viscosity of the mixture , lateral pressure coefficient, bulk modulus, residual expansion coefficient, relaxation time, Poisson's ratio, viscoelastic constants (Makarenkov, 2017).

However, to control the quality of granulated compositions, only 6 main indicators were entered in the CALS project: lateral pressure coefficient, external friction coefficient, adhesion coefficient, plastic strength, mixture volumetric viscosity coefficient and coefficient of residual expansion.

The defining parameters in the granulation process are those that characterize the ability of the material to change volume under the action of external loads (Thapa, 2019). The rheological properties of such systems are characterized by the kinetics of the increase in the limiting shear stress of the structure that arises in them during its formation. One of the criteria characterizing the kinetics of structure formation at low strain rates of granular compositions is the plastic strength parameter (Belem et al., 2020).

For each quality indicator, the corresponding instruments for their measurement have been added to the CQM system. Three devices were included in the system to measure plastic strength: the PIVOT automatic penetrometer, the K95500 digital penetrometer, and the PNR12 penetrometer.

Microprocessor-based digital penetrometer is designed to determine the consistency of greases, petroleum waxes, bitumen, pastes, creams and other products from solid to semi-liquid consistency. The measurement ends automatically after the time set by the operator. The equipment provides automatic installation of the cone on the surface of the sample. The penetrometer complies with all requirements of ISO 9001 and other relevant standards (Cruz-Domínguez et al., 2021).

5. Conclusions

The systematization of the processes of granulation of multicomponent materials has been carried out. It includes a three-level classification of granular products. The main quality indicators are identified, on the basis of which the choice of the granulation method is made. The most promising methods of granulation and their corresponding equipment (granulators) are systematized. The systematization carried out is the basis of the information model, on which an automated system for scientific research on the processes of granulation of multicomponent materials has been developed. The use of a promising CALS-system of computer support in scientific research makes it possible to unify information about the main methods of granulation and the equipment used. The use of CALS-technology significantly improves the access to the necessary information, computerization and automation of the workplace, as well as the relationship between specialists participating in research.

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