Reserch and Modeling of Filter Elements Production Process Control System Using Petri Nets

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Abstract
The purpose of this work is development and use of a mathematical apparatus for modeling the polypropylene fibrous filter elements (PFFE) production process control system based on the Petri net, which considers all stages of filter elements production at the enterprise. Real technological processes have a finite duration, which can be depicted graphically on Petri nets. This article reviews the possibility of using the Petri net for modeling the processes of polypropylene fibrous filter elements production, and also highlights a number of the Petri net advantages in modeling.

Keywords [1]
Petri net; production management system; modeling; technological process; sequence diagram

1. Introduction

The production of polypropylene filter elements by the method of pneumo-extrusion refers to process production, where each technological process is a sequence of technological operations, each of which cannot be interrupted at any time. It is very important to develop a model that considers all production processes and equipment operating cycle. Such model is necessary to increase the production process efficiency, its performance and the entire pneumo-extrusion method polypropylene filter elements production process improvement as a whole.

The processing of polymers, in particular polypropylene, is preceded by the design of the product pattern, the choice of the optimal method of processing, technological equipment design and manufacturing, polymer composition formulation development, its preparation and formation arrangement.

The actual processing of the polymer involves the products formation and their further processing in order to improve the polymer material properties (heat treatment, radiative crosslinking, etc.).

Simulation is the main research method in all fields of knowledge and the complex systems characteristics evaluation method for decision making in various fields of engineering is scientifically rationalized. Existing and projected systems can be effectively researched with the help of mathematical models (analytical and simulation) implemented on modern computers, which in this case act as the experimenter tool with system model [1]. Today, there are following main types of modeling: statistical modeling, information modeling, mathematical modeling, computer modeling, etc.

The purpose of this work is development and use of a mathematical apparatus for modeling the polypropylene filter elements production process control system where filter elements are made by pneumo-extrusion method based on the Petri net. Petri net considers all stages of polypropylene filter elements production by the pneumo-extrusion method at the enterprise; not only the order of action, but also the temporal characteristics, construction of a Discrete Petri net, it simulates the process of polypropylene filter elements production by the pneumo-extrusion method at the enterprise.

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Petri net (PN) is a mathematical apparatus for modeling dynamic discrete systems. First described by Carl Adam Petri in 1962. Most experts consider PN to be one of the most modern and most effective means of different classes systems graphical and mathematical modeling [2]. PN is a powerful tool for describing systems that use concurrency, synchronization, and collective resources, including industrial productions, with the purpose of coordinating processes and making operational decisions to manage them. PN is an extension of classical graph theory. PN theory gives the opportunity to specify systems using mathematical representation, the analysis of which helps to obtain important information about the structure and dynamic behavior of the modeled system [2, 3].

Currently, there are the following main types of Petri nets(PN): discrete PN, stochastic PN, functional PN, color PN, inhibitory PN, and hierarchical PN. There are advantages of PN in modeling: the model lucidity, the ability to perform analysis using computer technology, the hierarchical modeling possibility, as well as a high level of discrete event systems formalization. It should be noted that in recent years interest in PN has increased significantly [4].

2. The technological process of production

The technological polypropylene filter elements production process, made by the pneumo-extrusion method, consist of the following operations: production order placement, filter element calculation, template and raw materials preparation, extrusion, spraying template with polypropylene [5, 6]. The technological polypropylene filter elements production process, made by the pneumo-extrusion method, can be divided into four main technological stages: raw materials preparation stage; raw materials milling; The melting stage; Spraying stage. At each stage of the production process, a certain type of equipment is used. The developed classification scheme is shown in Fig. 1.

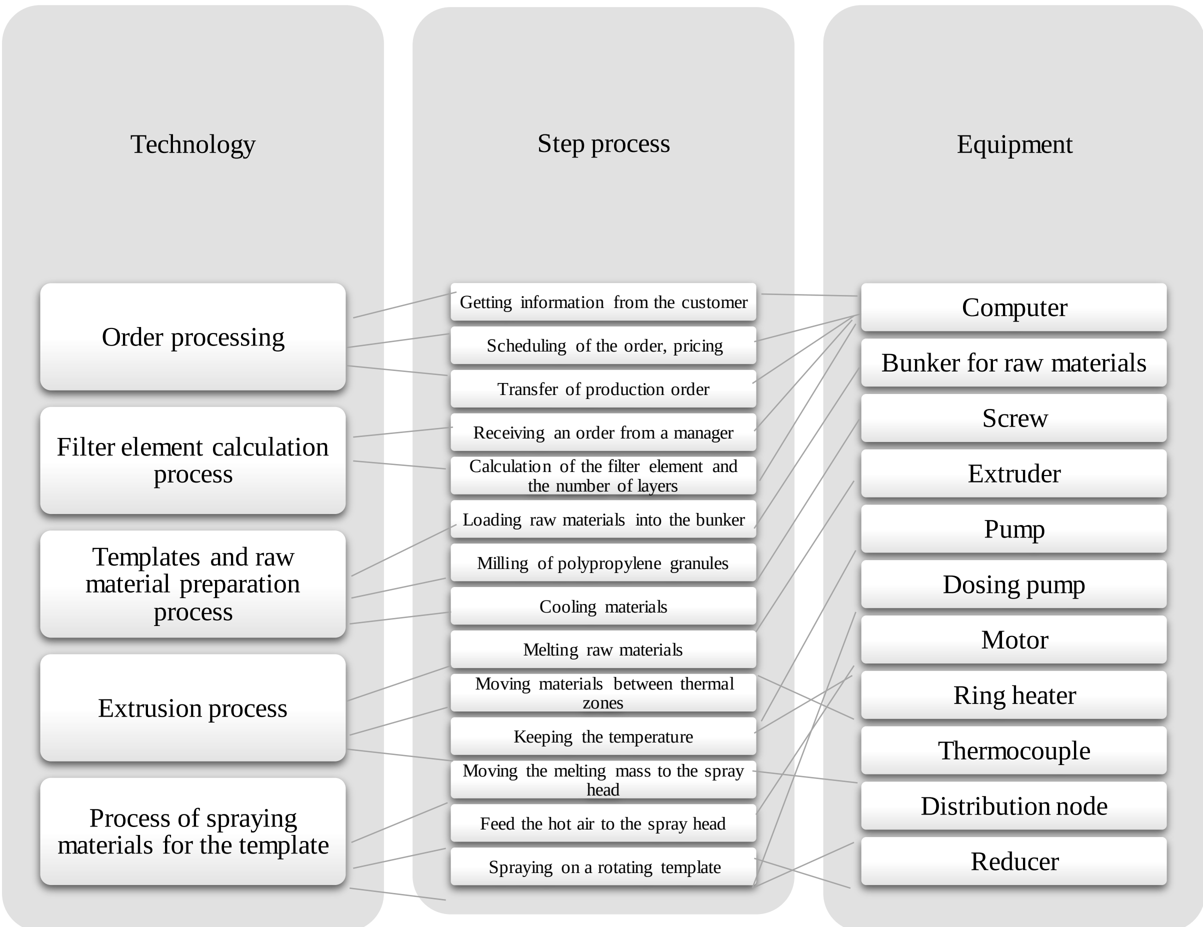

Figure 1: Technologies and equipment used in the polypropylene filter elements production

The technological polypropylene filter elements production process, made by the pneumo-extrusion method, involves several stages. The first stage is the preparatory work, which consists of the premises, auxiliary materials, equipment, raw materials preparation. After preparatory work, the stages of the technological process are sequentially carried out in accordance with the peculiarities of the pneumo-extrusion method production process, with control at each stage. The technological process by direct spraying of raw materials at the template [7]. The developed technological scheme of pneumoextrusion method polypropylene filter elements production is shown in Fig. 2.

PW – preparatory works stage
TP – main technological process stage
CT – technological control
CC – chemical control

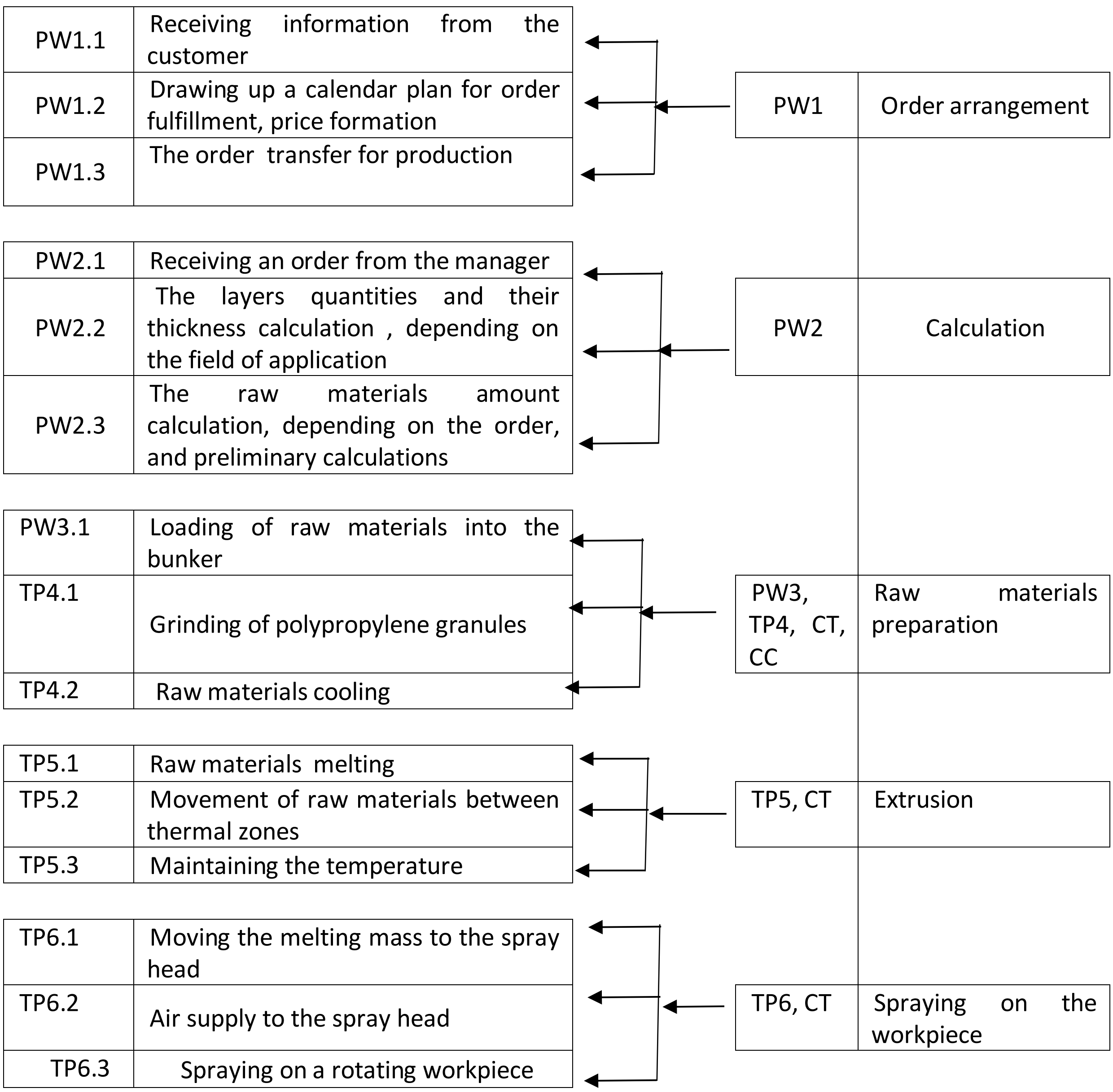

Figure 2: Technological scheme of polypropylene filter elements production by pneumoextrusion method

An important issue for human life and activity is the efficient use of water resources of the planet. An important process for the research is the stage of filtration. Models for describing water filtration differ in supplying of data, the ability to check the adequacy in the real conditions.

3. Model of filter elements for liquid and gas environments

It is known a technology which includes forming a backing layer of thick fibers and depositing fine fibers thereon. [8]

The task of the proposed technology is the creation of an inexpensive multi-layer filter element of the filter-separator that provides a high degree of purification of gaseous and liquid media, such as natural gas and liquid fuel, both from mechanical impurities and free moisture contained in the filtered medium in the form of aerosols.

The setted task is achieved due to the fact that a known multilayer filter element for liquid and gaseous media made of fibers of a thermoplastic polymer, preferably polypropylene, and consisting of alternating thick-fiber and fine-fiber layers is made by extrusion in the form of a hollow cylinder with a thick-fiber outer layer, Thick-fiber layers consist of fibers with a diameter of 100-150 microns, and fine-fiber layers - from fibers with a diameter of 1-5 microns.

Unlike the filter element according to the prior art, the present invention allows to create an inexpensive, efficiently operating filter element by:

- performing the filter element in the form of a hollow cylinder by extrusion (in the prototype, the tubular filter element is obtained by folding a pre-fabricated multilayer sheet of complex structure);
- the execution of the layer on the input side of the medium to be filtered with a thick-fiber, absorbing coarse mechanical impurities (in the prototype, the role of filter layers is performed by thin-fiber layers, and the thick-fiber layers serve as a spacer between them). The main purpose, as follows from the description, is to lining the fine- Its formation);
- alternating layers of the same density from a fiber with a diameter of 100-150 microns with layers, whose density decreases along the path of the filtered medium, and which are made of a fiber with a diameter of 1-5 microns.

The essence of this method is illustrated by the following example.

Example: Polypropylene fibers were extruded by forming a filter element in the form of a hollow cylinder consisting of seven layers. The characteristics of the layers are given in the table 1.

Table 1

Structure of filter element layers

Layer thickness in%	Layer density g / cc	Diameter of fiber µm
20	0,20	100-150
15	0,40	1-5
7,5	0,20	100-150
15	0,30	1-5
7,5	0,20	100-150
15	0,25	1-5
20	0,20	100-150

When the first thick-fiber layer, made of a fiber with a diameter of 100-150 microns, having a density of 0.20 g / cc and a thickness of 20% of the thickness of the filter element, is filtered, the filtered medium / natural gas or liquid fuel is freed from coarse mechanical impurities. In the next, a thin-fiber layer, whose density is 0.40 g / cc and fiber diameter is 1-5 microns, a process of finer purification takes place, as well as coarsening of water droplets contained in the filtered medium in the form of aerosols and the formation of water films. When the filtered medium leaves the fine-fiber layer in the thick-fiber layer, the laminar process turns into a turbulent layer, which is accompanied by a significant loss of kinetic energy, especially the heavier fractions of the filtered medium (water and impurities contained in it). At the same time, under the action of gravity forces, partial drainage of heavy fractions occurs to the lower part of the filter element and about 70% of the dropping water is removed from the filtered medium.

This is facilitated by the change in the turbulent process to laminar when the filtered medium enters a denser, finer-fiber layer with a density of 0,30 g / cc (the fourth in the direction of motion). In this layer, drops of water partially reach the bottom of the filter element.

Each time when the filtered medium passes from the fine-fiber layer to the thick-fiber layer (from the denser layer to the less dense layer), the laminar process becomes turbulent and the water drops and the water is removed from the medium to be filtered. The density of the fine-fiber layers decreases along the motion of the medium to be filtered, while the density of the thick-fiber layers remains constant.

The proposed design provides almost complete removal of mechanical impurities and allows to purify natural gas or liquid oil products from drip water by 97-98%.

The multilayer fibrous structure of the filter element according to the invention provides an efficient cleaning of liquid and gas media from mechanical impurities and free water present in the filtered medium in the form of aerosols. The use of fibers of a thermoplastic polymer, advantageously of a polymer, gives the filter element a high chemical resistance to a wide range of chemicals.

Compared to similar filter elements, the filter element in question is of low cost, easy to assemble and dismantle.

Models for describing water filtration differ one from another in supplying of data. Explored model of water filtration makes it possible to evaluate the advantages and disadvantages of forming a model of the filter with Thermal polymers in which the filtering partition is formed by continuous fibers Thermal concluded on the winding core. Advantages include the fibrous structure of the filter (fibers with a size of about 20 μm) and its material (polypropylene) ensures the appearance of an induced electric potential when the liquid moves through the filter layer, which in turn helps to destroy the double electrical layer of colloidal microparticles and fix them inside the filter layer. This effect causes a sufficiently high degree of purification of liquids from colloidal microparticles in a wide range of sizes from 0.1 to 5 μm.

4. Construction of the Petri net

Let us dwell on Petri nets with time constraints to analyze the polypropylene filtering fibrous elements production process. Real technological processes have a finite duration, which can be depicted graphically on time schedules. Because for the chemists who develop systems of periodic action and flexible automated production systems, the apparatus of Petri nets is little known [9].

Graphically, the Petri net is denoted as follows. Positions are represented by places, transitions are by thickened bars (barriers), marking by points inside places, and any number of points inside a place is allowed.

Discrete Petri nets is a two-part oriented graph supplemented by the characteristics of arcs and vertices represented by natural numbers [3, 11].

$$N_r = (P, T, F, M_0, \tau', \tau'')$$

where P = {pi}– positions set;

$T = \{t_j\}$ – transitions set;

$F \subseteq (P \times T)\ U\ (T \times P)$ – finite arcs set (indeterminacy function);

$M_0,\ P \rightarrow \{0, 1, 2, \dots\}$ – initial network markup;

$\tau' = \{\tau'_1, \tau'_2, \dots, \tau'_j,\}$ – transitions minimum delay times set;

$\tau'' = \{\tau''_1, \tau''_2, \dots, \tau''_j,\}$ – transitions minimum delay times set.

Petri nets are mainly used to model so-called interactive operations or interactions when several (at least two) technological devices are involved in the operation. The interaction simulations are performed in order to identify additional system resources, conflict situations for the further device interaction process control. However, Petri nets can successfully model much simpler operations, such as sequential processes in periodic devices. Of course, the Petri network models not its own technological processes but only their sequence as a result of the certain conditions fulfillment [10, 11].

Discrete Petri nets are one of the known extensions of basic Petri nets used to model systems and processes. Analysis of which must consider not only the order of action but also temporal characteristics.

Such networks are widely used in the research of technological and organizational management systems.

We define the technological operations (conditions) for modeling using Petri nets, presented in the form of a Table 2.

Table 2
Definitions of technological operations (conditions)

№	Technological operations	Designation of operations
1.	Packaged in granules' raw materials (polypropylene) shipt to production. At bunker entrance.	O_1
2.	Polypropylene is filled into the bunker of the 50 liters extruder. (***loading***)	O_2
3.	Raw material cooling in the loading area of the extruder.	O_3
4.	Screw in standby	O_4
5.	Polypropylene granules begin grinding under screw pressure (***milling)***	O_5
6.	Maintaining the temperature in the extruder zones	O_6
7.	Moving molten materials to the 1st thermal zone, heating to 150 ° C	O_7
8.	Moving to the 2nd thermal zone, further to heating - 250 °	O_8
9.	Moving to the 3rd zone - final heating with the maximum temperature - 320 ° C	O_9
10.	Moving to the last zone - the zone of the pipe arm, in this zone melt temperature 352 ° C (***melting***)	O_{10}
11.	Temperature control in the pipe arm, pumping melting mass	O_{11}
12.	Through the pipe arm the melting mass of the polypropylene enters the girder	O_{12}
13.	Air supply to the spray head of the dosing pump	O_{13}
14.	The melting mass enters the spray head of the dosing pump. (All four of them)	O_{14}
15.	The melting mass is sprayed on 4 templets (each head is sprayed on one templet) made of polyvinyl chloride (***spray***)	O_{15}

We define the states:

- the start of the technological process(TP) and
- the finish of the technological process.

Draw up a table of input and output conditions (Table 3, Table 4).

Table 3
Input and Output conditions

Equipment	System status (events)	Input conditions (operations)	Output conditions (operations)
Bunker for raw materials	S_1- start TP	O_1 O_2	O_3
	S_2- finish TP	O_3	O_4
Screw	S_3- start TP	O_4	O_5
	S_4- finish TP	O_5	O_4
Extruder	S_5- start TP	O_6	O_{10}
	S_6- finish TP	$O_7 O_8$ $O_9 O_{10}$	O_6
Pump	S_7- start TP	O_{11}	O_{12}
	S_8- finish TP	O_{12}	O_{11}
Dosing pump	S_9- start TP	O_{13}	O_{15}
	S_{10}- finish TP	$O_{14} O_{15}$	O_{13}

Table 4
Petri net

Equipment	System status (events)	Input conditions (operations)	Output conditions (operations)
Bunker for raw materials	t_1	P_1 P_2	P_3
	t_2	P_3	P_4
Screw	t_3	P_4	P_5
	t_4	P_5	P_4
Extruder	t_5	P_6	P_{10}
	t_6	$P_7 P_8$ $P_9 P_{10}$	P_6
Pump	t_7	P_{11}	P_{12}
	t_8	P_{12}	P_{11}
Dosing pump	t_9	P_{13}	P_{15}
	t_{10}	$P_{14} P_{15}$	P_{13}

The described situation is modeled by the Petri net, which is presented in the form of a table (Table 4) and its graphical representation (Fig.3). As can be seen from table 3, there is a one-to-one correspondence is established between technological operations and network positions, as well as between equipment states and network transitions:

$$\{O\} \leftrightarrow \{P\};$$

$$\{\text{Technological operation}\} \leftrightarrow \{Position\};$$

$$\{S\} \leftrightarrow \{t\};$$

$$\{System\ status\ \} \leftrightarrow \{Transition\};$$

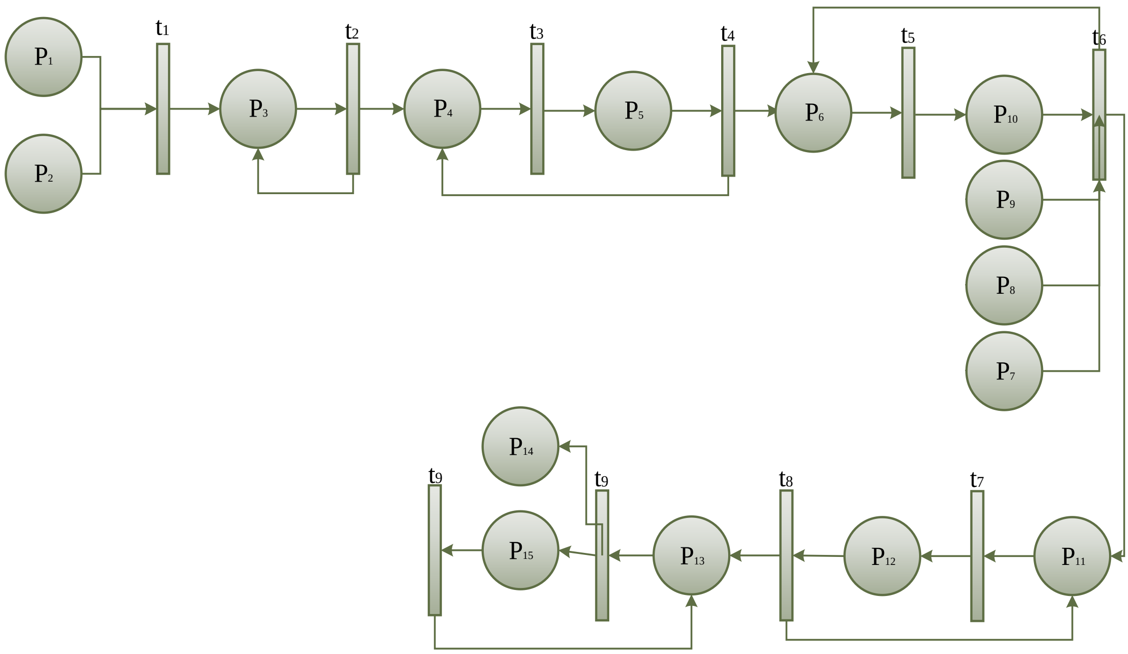

Figure 3: Petri network, which simulates the technological polypropylene filter fibrous elements production process

5. Optimal flex fiber development algorithm

Conducted experimental and theoretical researches have made it possible to form a universal algorithm (Fig. 4) for obtaining the optimum fiber thickness, depending on the technological process physical characteristics. The presented algorithm allows solving the following problems:

- supports the creation of polypropylene fibrous filtering elements formulations with specified consumer characteristics, depending on the application field and optimal cost;
- forms recommendations on the filtering characteristics of the received polypropylene fibrous filter elements according to current standards (DSTU, TU, etc.);
- provides search of optimum physical characteristics at all stages of technological process;
- analyzes the final product quality, identifies technological problems and suggests solutions.

The algorithm of the optimum polypropylene fibrous filter elements fibers thickness as the main task requiring automation is presented as a block diagram in Fig. 3.

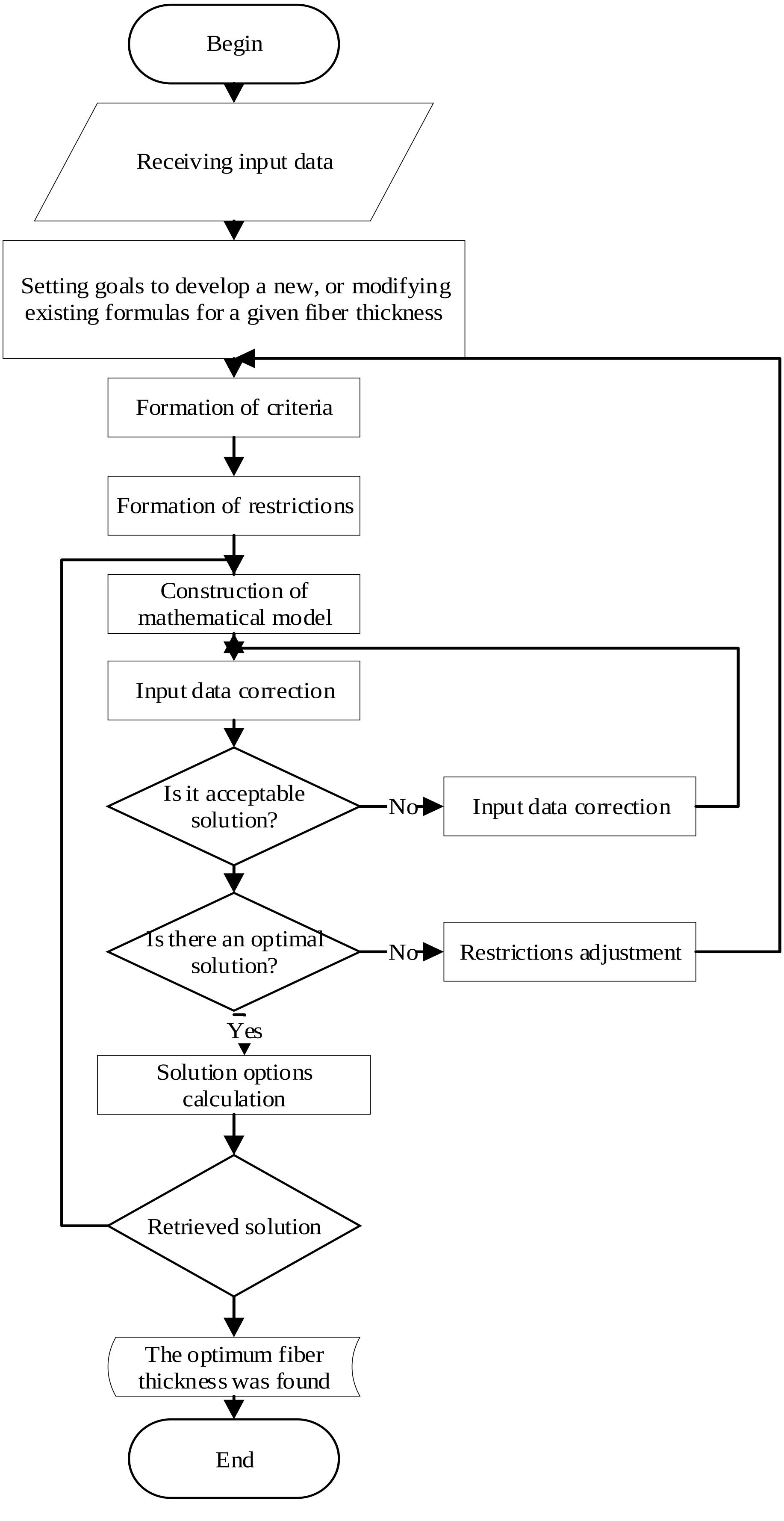

Figure 4: The polypropylene fibrous filter elements optimum thickness modeling algorithm

The presented algorithm can be used to select the fiber structure of a polypropylene filter element depending on the application field.

6. Conclusions

Models of water filtration makes it possible to evaluate the advantages and disadvantages of forming a model of the filter with Thermal polymers in which the filtering partition is formed by continuous fibers Thermal concluded on the winding core.

Advantages include the fibrous structure of the filter.

The disadvantages are when we form a pore with a gas bubble, we can more accurately determine the diameter of the pore that we want to get. And in a fiber filter this is achieved by increasing or decreasing the packing density of the fibers in the layers of the filter and the thickness of the fiber itself. And it can be programmed only in the laboratory by an experimental method. Not every production can afford the choice of parameters through laboratory research.

We have reviewed the polypropylene fibrous filter elements technological production process control system modeling using the Petri net. Modeling is one of the main research methods in all fields of knowledge and a scientifically justified method for evaluating the complex systems characteristics used in various fields of engineering decision making. Petri nets are simple but effective in analyzing production systems method. A model of the polypropylene fibrous filter elements production process has been constructed where all technological processes are managed. This made it possible to construct an algorithm for designing the polypropylene filtering elements fiber optimum thickness.

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