Outlook for using modern rotary screw systems in industry

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Abstract. The use of rotary screw systems began in the 30s of the XX century as they were part of the emerging military industrial complex. Currently, rotary screw systems are used in a number of sectors of the national economy (in mechanical engineering, in the food industry, in gas and oil production, applicable in such industries as oil refining, chemical industry, agriculture, building industry, construction, etc.). However, the scale of their application is not commensurate with the benefits they provide compared to other types of systems, the functioning of which is based on different technological principles. The paper presents an outlook on the introduction and use of technology and equipment in industry, which will use the original designs of rotary screw bodies with a horizontal arrangement of the rotation axis as working bodies, which will reduce energy costs, improve technical and economic indicators, simplify maintenance and increase productivity. The paper presents the perspective of the use of rotary screw systems in the industry using the example of the cement industry on the example of a design of a furnace with a grate cooler for the clinker production. The proposed design has great scientific and practical significance, which is confirmed by the obtained patents. The presented technology for manufacturing screw bodies and optimizing their design parameters allows outlining and implementing an innovative way to develop cement production. As the results of our research, we not only developed the technology of assembling screw bodies for single and serial production, but also performed work on optimizing their design parameters.

1. Introduction

Rotary screw systems belong to the fourth (highest) class process (Figure 1), that is, when the product is processed in space. Technologically efficient and equivalent are all points enclosed in a given volume of processing medium [1-3]. Any point of the work space A, B, C is capable of affecting any point of the processing object a, b, c, d.

There are 63 cement enterprises operating in today's Russian cement industry. The total capacity of cement enterprises is 101.3 million tons. Cement production is 68.8 million tons. Capacity utilization factor of the existing equipment is 68% [4].

The balance of cement production and consumption in thousand tons is given in Table 1.
**Figure 1.** Visual image of fourth-class process: 1 - processing object, 2 - processing medium; A, B, C - any points of working volume, a, b, c, d - points of processing object.

**Table 1.** The balance of cement production and consumption in thousand tons.

| Region                                 | Production | Import | Export | Consumption | Balance (+/−) |
|----------------------------------------|------------|--------|--------|-------------|---------------|
| Total for Russian Federation, including:| 68 424     | 4799   | 1752   | 71 470      | −3046         |
| European part of Russian Federation    | 50 564     | 4169   | 1460   | 53 606      | −3042         |
| CFD                                    | 17 731     | 1207   | 539    | 22 632      | −4900         |
| NWFD                                   | 4496       | 1668   | 4      | 6691        | −2195         |
| VFD                                    | 16 381     | 657    | 12 597 | 3783        |               |
| SFD                                    | 9560       | 975    | 182    | 8003        | 1557          |
| NCFD                                   | 2396       | 319    | 78     | 3683        | −1287         |
| Asian part of Russian Federation       | 17 860     | 630    | 292    | 17 864      | −4            |
| UFD                                    | 6767       | 0      | 96     | 7142        | −375          |
| SFD                                    | 8729       | 246    | 195    | 8103        | 626           |
| ДВФО                                   | 2364       | 384    | 1      | 2618        | −254          |

One of the most important performance indicators of cement industry enterprises is the specific consumption of energy resources for the production of clinker and cement [5-6]. As part of the cost of cement, depending on the method of its production and technical equipment, the share of fuel and electricity costs is 28 to 45% [7-10].

The lowest average consumption of energy resources occurs with a dry method of production [11-12]. Among all cement plants, according to this indicator, the enterprises “Peterburgcement” stand out, where waste containing oil shale is used as raw material, and “YuUGPK” LLC, where up to 35% of metallurgical slags of blast furnace and open-hearth production are included in the raw material charge [13-15].

Average energy consumption by production methods is given in Table 2.

**Table 2.** Average energy consumption by production methods.

| Production method | Commissioning | Average annual specific fuel consumption | Average annual specific power consumption | Average reduced power consumption |
|-------------------|---------------|------------------------------------------|------------------------------------------|---------------------------------|
| Dry               | Till 1989     | 146.6                                    | 154.6                                    | 198.2                           |
|                   | After 2008    | 106.4                                    | 122.5                                    | 147.4                           |
| Wet               | After 2008    | 189.2                                    | 121.9                                    | 229.6                           |
| Combined          | -             | 147.2                                    | 99.6                                     | 180.6                           |
In the 1990s, due to a sharp decline in demand for cement, factories were forced to suspend and decommission production lines. In the period from 1988 to 2008, new cement production facilities were not commissioned, while 7 cement plants were decommissioned, a total of 90 different technological lines. The decommissioned technological lines of cement plants were equipped with morally and physically obsolete equipment; depreciation of fixed assets was 68 to 88%. Specific power consumption on these lines was 90 to 160 kWh / t of cement, while the industry average consumption of 113 kWh per 1 ton of cement.

Since 2008, an unprecedented activity has begun in the construction and commissioning of new modern lines, predominantly for dry production. So far, 23 technological lines with a total capacity of 32.6 million tons have been put into operation, including 19 technological lines operating on dry technology and 1 line of a combined production method.

At the same time, morally and physically obsolete technological lines of the wet production method are still in operation in the cement industry in Russia [16-17]. Ten dry production lines and two combined production lines are also morally and physically obsolete, requiring modernization or decommissioning.

2. Materials and Methods
The basis of the study is the design for the production of clinker furnace 5 × 185 m with a grate cooler "Volga 75" with a capacity of 1800 tons/day with an average annual specific nominal fuel consumption ~ 201 kg/t of clinker. Wet rotary furnaces are shown in Figure 2.

![Figure 2. Example of Wet Rotary Furnace: 1 - Smoke Exhauster, 2 - Electric Filter, 3 - Slurry Feeding Device, 4 - Heat Exchangers (Chain Curtain), 5 - Shroud, 6 - Furnace Body, 7 - Furnace Drive, 8 - Roller Support, 9 - Burner, 10 - Clinker Cooler.](image)

The rotary furnace is a steel drum, which rests through the shrouds on roller supports and rotates at a frequency of 1 to 1.5 rpm. The furnace has a slight slope (3.5 to 4.0%) to allow the material to move to the discharge end. The furnace operates according to the countercurrent principle. The slurry is fed through the slurry pipe to the cold part of the furnace. Hot furnace gases and gases emitted from the material move towards the material from the discharge end of the furnace. The material, moving through the furnace, is heated to the sintering temperature of the clinker ~ 1450 ° C, and the gas stream moving to the cold end reduces its temperature from ~ 1800 ° C in the flare to ~ 200 ° C at the outlet of the furnace.

Such equipment is characterized by significant power consumption due to large dimensions, losses in the heat exchange process, limitations of technological capabilities, complexity of operation and large mass.

The elimination of these disadvantages can be the development and implementation of technologies and equipment, which will use the original designs of rotary screw bodies with a horizontal arrangement of the rotation axis as working tools, which will reduce energy consumption, improve technical and economic performance, simplify maintenance and increase productivity.

Figure 3 shows the developed diagram of a rotary furnace for the preparation of cement clinker with a screw body.
This brings great scientific and practical significance. The development of a technology for the manufacture of screw bodies and the optimization of their design parameters is the most important task, since it allows to outline and implement an innovative way of developing cement production.

4. Results

In the results of the studies, we not only developed the technology of assembling screw bodies for single and serial production, but also performed work on optimizing their design parameters: the number of curved surfaces of the screw body of the rotary furnace should be more than \( n > 6 \), and the width of the screw surface should be more than 400 mm.

At the same time, it should be noted that the features of the proposed design of screw body include:

- broken or smooth helical surfaces are formed along the inner perimeter of the screw bodies along their entire length, which ensures disturbance of stationary flows of raw cement mass particles, increase of productivity and expansion of technological capabilities.
- the design of screw bodies allows to ensure successive rarefaction of flows of raw cement mass particles during transition from one section to the next one as they move from cold end of furnace to the hot one, to increase productivity and to expand technological capabilities.

The results of research on the technological and theoretical bases for improving the operational characteristics of equipment for cement production allow us to conclude that there are clear advantages of using rotary-screw systems in cement production, namely, first of all, increased productivity and a significant reduction in energy consumption.

Calculating the cost of cement production by dry and wet production methods, taking into account the cost of borrowed capital attracted for the implementation of new projects, justifies the need for the cement industry to switch to modern technologies, one of which may be the use of rotary screw systems.

The results of the cost analysis based on expert estimates of the cost of production for all cement plants of Russia based on practical experience and taking into account particularities of the technologies, standards and resources, organization of production and other factors, according to the Federal Agency for technical regulation and Metrology presented in Figure 4. The analysis was made
on the basis of current production, projects, construction of new production facilities, projects on reconstruction of existing enterprises.

![Graph showing production costs of 1 ton of cement in Russia from 2013 to 2020](image)

**Figure 4.** Production costs of 1 ton of cement in Russia in 2013 to 2020, RUB/t (actual and projected).

The estimate of cement production costs at Figure 4 takes into account the impact of the debt burden on credit resources (interest on loans), which for new production enterprises have a significant weight in the structure of total costs.

Despite the high investment associated with the construction of new production facilities, the need for new construction is driven by a number of economic advantages.

### 5. Discussion

In conclusion, the main economic and environmental aspects of the use of rotor screw systems in cement production identified by us during the study can be briefly described. Such aspects are as follows:

1. **Energy efficiency**, that is, reducing the cost of fuel and energy resources and directly in the production of cement. Application of rotor screw systems in dry process cement production will reduce the cost of fuel and energy resources by an average of 30 to 40% compared to the technologies currently used.

   In particular, reduction/minimization of specific heat consumption for clinker firing can be achieved as follows (Table 3).

   At the same time, predicted technological indicators obtained using rotary screw technologies will be as follows (Table 4).
Table 3. Reduction/minimization of specific heat consumption for clinker firing can be achieved as follows.

| Method/Equipment                                                                 | Applicability                                    |
|---------------------------------------------------------------------------------|--------------------------------------------------|
| Use of rotor-screw systems in dry production, optimization of heat exchanger     | For newly built and modernized enterprises        |
| stages according to characteristics of raw materials used                       |                                                  |
| Use of furnace system of optimal configuration and stable mode of furnace unit   |                                                  |
| operation in accordance with set parameters by:                                 |                                                  |
| - optimizing control system, including automatic computer control and automation | For newly built and modernized enterprises        |
| of process control;                                                             |                                                  |
| - using modern systems of homogenization, dosing and supply of materials and     | For newly built and modernized enterprises        |
| fuel to furnace                                                                  |                                                  |
| Recovery of excess heat from furnace system, especially from clinker cooler,    | For newly built and modernized enterprises        |
| use of recovered heat for drying of raw materials                                |                                                  |
| Use of high-calorific fuel with characteristics that have a positive effect on   | For all enterprises                               |
| reducing specific heat consumption                                              |                                                  |
| Minimization of atmospheric air leaks in furnace system                          | For all enterprises                               |
| Minimizing gas flow into the bypass system                                       | For enterprises of dry method of cement production|
| Minimizing moisture content of raw sludge by replacing some of natural          | For enterprises of wet method of cement production|
| components with man-made materials and using sludge thinners                    |                                                  |

Table 4. Projected process parameters obtained using rotary screw technologies.

| Process parameter                        | Value, MJ / t | Value, kg n.f. / t clinker |
|------------------------------------------|---------------|---------------------------|
| Specific heat consumption for clinker    |               |                           |
| roasting:                                |               |                           |
| - for dry production plants              | 3550 to 4120  | 90 to 160                 |
| - for wet production plants              | 5750 to 6900  | 196 to 235                |
| - for combined production plants         | 3950 to 4540  | 135 to 155                |

1. Increase in labor productivity (decrease in labor costs) due to the automation of production processes, which allows you to work with a smaller number of production personnel in comparison with outdated industries with a low level of automation. Accordingly, the total cost of personnel labor is reduced, and the rate of output per employee increases.

2. Building a system to optimize process control

The introduction of such a system will require investments, according to a number of estimates, up to 300,000 euros to automate the firing process, based on the control of emissions of harmful substances using computer technologies, and additional investments are required for the installation of measuring and dosing equipment at the plant.

3. Implementation of environmental management systems (EMS)

The costs of implementing an EMS depend on many factors, including the availability of a workable quality management system, the level of training of personnel, the size of the enterprise
(number of employees), the decision of the management to attract consulting companies, or the implementation of an environmental management system in-house. According to some estimates, for large organizations, the costs of a full-scale implementation of EMS in Russia can reach 1 to 1.5 million rubles. (not including staff labor). At the same time, it should be emphasized that the development and application of basic EMS methods, as a rule, do not require the involvement of external consultants, but they provide many advantages in the management of priority environmental aspects.

6. Conclusions
The results of our research are confirmed by the corresponding patents of the Russian Federation and publications in Russian and foreign journals, including journals indexed in the Scopus and WoS databases.

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