Evaluation of the Technical and Economic Efficiency of Oil-Contaminated Wastes Recycling System Based on DEA-Method

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Abstract. The article presents a method for analysis of technical and economic efficiency of oil-contaminated wastes (OCW) recycling system. The approach is based on a comparative analysis of the values of costs and profits for the processing of waste in a particular storage facility using a specific processing technology for various combinations of storages and technologies. The set of compared combinations was compiled on the basis of data on the actual processing technology applied for the OCW recycling in the particular storage and also for the technology selected using a special evaluation algorithm. The algorithm for optimization of the OCW recycling system includes the determination of the reuse potential assessments for OCW storage facilities, as well as evaluation of environmental safety and energy efficiency assessments for processing technologies. The calculation of efficiency estimates is carried out using the DEA method, which is widely used as a method of multi-facto­rial assessment of the efficiency of production systems, using specially developed software.

1. Introduction
Development and optimal management of waste recycling systems in different branches of industry (including oil and gas industry) is an important task of the current stage of socio-economic development of modern societies. The solution of this problem is based on the concept of a ‘closed-loop economy’, where industrial and household wastes are considered as production resources to be returned to circulation [1-6]. Criteria for the efficiency of waste reuse in a circular economy are formulated on the basis of heterogeneous indicators, the main of which (environmental, economic, social and technical) are presented in the review [1]. The environmental indicators considered in [1] include parameters that characterize carbon emissions [2] and pollutants into the air, water, and soil [3]; energy efficiency indicators [4,5] determine the efficiency of energy consumption and production in the waste recycling processes, and non-energy indicators include material balance estimates, economic estimates, and social factors [6]. An important challenge in this case is the development of methods for obtaining overall (generalized) efficiency assessments, on the basis of which it is possible to formulate and solve the problem of optimal management of the waste recycling system.
In [7-9], it is proposed to calculate technical and economic indicators of the OCW recycling efficiency based on the Cost-Benefit Analysis method. This approach determines the balance of all components giving benefits (material flows and other non-material advantages) on the one hand, and all components of costs (or other factors estimating as disadvantages) on the other.

The purpose of this work is to develop a methodology for technical and economic analysis of efficiency of OCW recycling system, which includes storages and technological plants for their processing. Reuse potential, environmental safety, and energy efficiency are used as the basic criteria for evaluating the efficiency of the OCW recycling system.

2. Algorithm for evaluation of efficiency of OCW recycling system based on DEA-method

In [10, 11] we propose a procedure for multi-criteria optimization of the oil-contaminated waste recycling system based on the Data Envelopment Analysis (DEA) – the special method for multi-factor evaluation of the efficiency of production systems [12-15].

To calculate the efficiency assessments $D_{fh}, \ f = 1,N, \ h = 1,H$ for OCW recycling in the $f$-th storage using the $h$-th technology, the solution of the special mathematical programming problems (MPPs) based on the Super-efficiency model of the DEA-method are carried out according to the algorithm shown in figure 1. $N$ OCW storages in existing recycling system, described in detail in [7,8], represent compared objects or decision making units (DMU). Every $\alpha$-th MPP ($\alpha = 1,5$) consists in searching for the maximum of the corresponding objective functions $D_{fh}^\alpha, \ f = 1,N, \ h = 1,H, \ \alpha = 1,5$, representing the ratio of weighted sum of output parameters (that positively affect the efficiency assessment $D_{fh}^\alpha$) to the weighted sum of input parameters that negatively affect the efficiency assessment $D_{fh}^\alpha$. The MPP solution provides the values of assessments $D_{fh}^\alpha, \ f = 1,N, \ h = 1,H, \ \alpha = 1,5$, distributed over the interval $[0,\infty)$.

The analysis of the obtained values of $D_{fh}^\alpha, \ f = 1,N, \ h = 1,H, \ \alpha = 1,5$, makes it possible to identify the optimal combination of the OCW recycling technology and the OCW storage facility in the analyzed groups. However, the obtained efficiency assessments based on DEA-method are relative and dimensionless, that leads to the need to calculate additional technical and economic indicators that characterize the efficiency of the selected OCW processing technology in standard economic terms.

The list of OCW storages, as well as the corresponding existing and proposed OCW recycling technologies are given

![Figure 1. Algorithm for evaluation of efficiency of OCW recycling system based on DEA-method.](image-url)
in table 1. The proposed technologies are selected according to the evaluations $D_{i}^{n}$ of efficiency of OCW recycling system using algorithm presented above and described in details in [10, 11].

**Table 1. OCW storages and recycling technologies.**

| OCW storage | Existing recycling technology | Selected recycling technology (using algorithm in fig.1) |
|-------------|-------------------------------|---------------------------------------------------------|
| Storage №1  | MegaMACS (three-phase centrifuge) | UBPS-10 (granulator)                                    |
| Storage №2  | KTO 2000 BMC (incinerator)     | UBPS-10 (granulator)                                    |
| Storage №3  | BRNS-50 (gravidynamic separator) | UOG-15 (hydrocyclone)                                  |
| Storage №4  | INSTAB (sorbent Econaft)       | UOG-15 (hydrocyclone)                                  |
| Storage №5  | Fortan 4 (pyrolysis)           | UOG-15 (hydrocyclone)                                  |
| Storage №6  | PUTIDOIL (bioremediation)      | MegaMACS (three-phase centrifuge)                      |
| Storage №7  | TDU FACTOR-2000               | UOG-15 (hydrocyclone)                                  |
| Storage №8  | Active sludge (bioremediation) | UBPS-10 (granulator)                                    |

In the framework of the study presented below, a comparative calculation of costs and benefits is performed for OCW storages and recycling technologies represented in table 1.

3. **Approach for evaluating technical and economic performance indicators of the OCW recycling system**

This section provides an approach for evaluating technical and economic performance indicators of OCW recycling system. The existing recycling system is compared with the system where the various combinations of storages and technologies were selected using the algorithm (see Section 2) providing for all combinations the best possible values of the following criteria: reuse potential, environmental safety, energy efficiency. In addition to these criteria it is proposed to consider the technical and economic performance indicators described below.

3.1. **Criteria and main parameters**

The list of criteria and corresponding main parameters used for their assessments is given in table 2.

**Table 2. Criteria and main parameters for the evaluation of waste recycling system.**

| Criterion                                      | Main parameters                                      |
|-----------------------------------------------|------------------------------------------------------|
| $i=1$ OCW reuse potential                    | $k_{11}$ – duration of the recycling process, [hours] |
| $i=2$ Energy efficiency of the OCW recycling process | $k_{21}$ – unit energy costs for delivery, [rub. per tons] |
| $i=3$ Environmental safety of the OCW recycling process | $k_{31}$ – gross greenhouse gas emissions (carbon dioxide and methane), [tons] |
3.2. Approach to the comparative analysis
Comparison of the effectiveness of the existing and proposed recycling systems is carried out by calculating the following indicators:

- total costs \( S^0_f \), \( S^1_f \) of recycling OCW in \( f \)-th storage \( f=1,N \) for existing and selected technologies, respectively, [rub.]:
  \[
  S^0_f = \sum_i \sum_h k^0_{ih} \cdot c^0_{ih}, \quad S^1_f = \sum_i \sum_h k^1_{ih} \cdot c^1_{ih}, \quad f=1,N, \quad i=1,3, j_1=1,4, j_2=1,2, j_3=1,5
  \]
  (1)
where \( k^0_{ih} \) — values of parameters calculated for the existing technology of recycling OCW in \( f \)-th storage, \( k^1_{ih} \) — values of parameters calculated for a technology selected by evaluation algorithm for recycling OCW in the \( f \)-th storage from the considered group consisting of \( N \) storages, \( c^0_{ih} \), \( c^1_{ih} \) — cost weight coefficients.

- unit costs \( s^0_f \), \( s^1_f \) of recycling OCW in \( f \)-th storage \( f=1,N \) for existing and selected technologies, respectively, [rub. per tons]:
  \[
  s^0_f = \frac{S^0_f}{M^f}, \quad s^1_f = \frac{S^1_f}{M^f}
  \]
  (2)
where \( M^f \) — mass of OCW located in the \( f \)-th OCW storage to be recycled.

- difference \( \Delta s^f \) in unit costs of recycling OCW in \( f \)-th storage \( f=1,N \) for existing and selected technologies, [rub. per tons]:
  \[
  \Delta s^f = s^0_f - s^1_f, \quad f=1,N
  \]
  (3)

- relative deviation \( \delta s^f \) of unit costs for recycling OCW in \( f \)-th storage \( f=1,N \) for existing and selected technologies, [%]:
  \[
  \delta s^f = 100 \left( \frac{s^0_f - s^1_f}{s^0_f} \right), \quad f=1,N
  \]
  (4)

- the average difference in unit costs \( \overline{\Delta s}^f \) for a group of OCW storages, consisting of \( f=1,N \) objects, [rub.]:
  \[
  \overline{\Delta s}^f = \frac{\sum \Delta s^f}{N}
  \]
  (5)

- the average relative deviations in unit costs \( \overline{\delta s}^f \) for a group of OCW storages, consisting of \( f=1,N \) objects, [%]:
  \[
  \overline{\delta s}^f = \frac{\sum \delta s^f}{N}
  \]
  (6)

4. Results and discussions
The section demonstrates example of computations of indicators described in Section 2 for OCW recycling system represented in table 1. The values of indicators obtained using (1)-(6) are shown in in table 3.
Table 3. Results of calculation.

| OCW storage № | Total costs $S^{0j}$ | Unit costs $S^{1j}$ | Change in unit costs $\Delta S^{1j}$ | $\delta S^{1j}$ |
|---------------|----------------------|---------------------|------------------------------------|----------------|
| Storage №1    | 5315.0               | 23750.2             | 0.684                              | -2.373         | -346.850       |
| Storage №2    | 9506.7               | -6670.4             | 5.464                              | 9.297          | 170.165        |
| Storage №3    | -33095.7             | -46734.1            | -4.257                             | 6.643          | 138.483        |
| Storage №4    | 514.5                | -1104.0             | 1.698                              | 5.341          | 314.584        |
| Storage №5    | 738.8                | -284.3              | 4.797                              | 6.643          | 138.483        |
| Storage №6    | 56063.0              | -63075.0            | -2.580                             | 4.872          | 212.507        |
| Storage №7    | 1699.8               | -4241.8             | -5.292                             | 4.943          | 349.547        |
| Storage №8    | 38475.3              | 18466.5             | 5.073                              | 2.638          | 52.004         |

The average value of difference in unit costs $\bar{\Delta S^{1j}}$ for a group of OCW storages, consisting of 8 storages is equal to:

$$\bar{\Delta S^{1j}} = \frac{\sum \Delta S^{1j}}{8} = 4.14 \text{ rub. per tons.}$$

The average value of relative deviations in unit costs $\bar{\delta S^{1j}}$ for the same group of OCW storages can be obtained as:

$$\bar{\delta S^{1j}} = \frac{\sum \delta S^{1j}}{8} = 116.46\%.$$ 

The analysis of the results confirms the presence of a significant positive economic effect that consist in:

- the possibility of transferring some of the technologies from the "unprofitable" category to the "profitable" category by using them for the disposal of OCWs in storages with reuse potential.
- the reduction of average unit cost of OCW recycling by 4.14 thousand rubles per ton within the analyzed recycling system.
- increasing the average relative profit of the OCW recycling by 116.46% in comparison with the traditional operating of the system.
- the possibility of full implementation of OCW reuse potential in the considered storages as sources of secondary raw materials.

The value $\bar{\delta S^{1j}} > 100\%$ means the possibility of extracting additional income from the OCWs recycling by increasing the yield of useful recycling products.

The analysis of obtained results confirms also the correctness of criteria used in algorithm for evaluation of efficiency of OCW recycling system as the basic criteria for optimizing the OCW recycling system.

5. References

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