The Criterion of Permissible Deviations Accounting Batches of Petroleum Products

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Abstract. The analysis of the existing process of assessing the reliability of production accounting of operations for the movement of oil and petroleum products in the oil refining industry from the entrance of raw materials till fixing the mass of the petroleum product shipped to the consumer has been carried out. The well-known criteria for the assessment of the reliability of production accounting of petroleum products in the process of the technological chain of its production and with the further movement of batches of petroleum products are considered. Analyzed the practice of applying existing criteria. Evaluation criteria were selected, and options were proposed for their implementation in software solutions for metering the mass of petroleum products in commodity parks. The approach to the work of operational staff with the proposed criterion is described. The conclusions about the need to include a number of measures in the process of production accounting to increase its reliability and control of material balance are given.

1. Introduction

Issues related to the organization of reliable metering of the petroleum products mass at oil refineries and tank farms in Russia are more relevant today than ever. This is determined primarily by the structure of the oil refining industry in Russia. So almost all refineries and tank farms are concentrated in several large oil companies. They use a management system in which the parent company makes an assessment of the effectiveness, planning and financing (lending) of subsidiaries on the basis of reports that reflect the results of the company's material balance sheet.

There is an important point here – this reporting is prepared and provided to the parent company by the subsidiary itself. The quality and relevance of the reality of these statements are selectively monitored by extensive audits. But systematic work to achieve full transparency and reliability of the reporting information can only be built on the subsidiary company itself using the control tools of the parent company.

There is a difficult situation due to the fact that the data from the metering devices set only the starting point for the formation of final reports, and if it is impossible to obtain beautiful final reports, this information is considered the least reliable. That is, the gap between the results of production accounting and the data obtained as a result of the material balance is the space for unfair manipulations with the accounting data.

In addition to analyzing the current state of accounting at refineries, this article justifies the choice of criteria to be applied in production accounting when generating data both for the time period along
the production chain and for each operation for moving oil products. This ensures the reliability of the results of production accounting and reduces the opportunity for data manipulation when reducing the material balance of the facility.

In [1-9] various aspects of the methodology of production accounting and material balance reducing are considered.

2. Current problem state

The reliability of oil product accounting today is determined on the basis of the compliance of the primary production data (production accounting) and the results obtained in the process of reducing the material balance. The results of these two processes do not always coincide.

*Production accounting* is the process of performing, fixing and collecting information on measuring quantities of raw materials and petroleum products at all stages of their production, movement and storage. On the basis of production accounting, as a particular example, a picture is formed on the efficiency of technological objects of production (mainly technological installations and commodity parks – CP). Primary production data (PPD) is formed as a result of production accounting. PPD can be the result of measurements, for example, with the help of automatic metering devices in automated process control systems (APCS). Sometimes PPD can be indications of automated measuring tools presented as an aggregation of indications of several means of measuring parameters of a petroleum product and an algorithm that recalculates these parameters into mass. PPD can be measurements by certified methods of the amount of petroleum products in tanks and other containers. Also acceptance reports, normative or design values may be referred to the primary production data, with the proviso “for limited use”. On the basis of the primary production data, information on residues of petroleum products in the CP, pipelines, equipment or in containers (railway tanks, tankers, cans ...) and on the amount of petroleum products moved from one technological facility (inside the facility) to another for the required period of time is generated.

The following expression can be considered as the criterion of the production accounting accuracy:

\[ \sum M_{en} + \Delta M_{rest} - \sum M_{prod} + \sum M_{toll} = N, \]

where:

- \( \sum M_{en} \) is whole raw materials and components mass accepted for production of commercial products;
- \( \Delta M_{rest} \) is change in residues (mass) of previously recorded raw materials and components in CP, pipelines, equipment and containers;
- \( \sum M_{prod} \) is the mass of all the shipped products (shipment by pipeline, road, rail and water transport, as well as in other containers with small packaging);
- \( \sum M_{toll} \) is mass of raw material, components and petroleum products losses on all of the production, storage and shipment stages.

\( N \) is some value of mass which should tend to 0, but may differ from 0 due to the fact that the terms of expression (1) are determined with an error at each specific moment. If production accounting data is gathered for a sufficiently long period of time, this value loses a significant difference from zero. In real production, this situation is unattainable, therefore, expression (1) can be used to find \( N \), i.e. to assess the correctness of production accounting.

The material balance reduction, in turn, is the process of correcting the primary production data in order to ensure the following nominal equality (given in simplified form, the issue was considered in detail in [1]):

\[ \sum M_{en} + \Delta M'_{rest} = \sum M_{prod} + \sum M'_{toll}, \]

where:
\[ \sum M_{en} \] is mass of whole raw materials and components accepted for commercial products manufacturing;
\[ \Delta M'_{rest} \] is corrected value (obtained by production accounting) changes in residues of previously recorded raw materials and components in CP, pipelines, vehicles and packaging;
\[ \sum M_{prod} \] is the mass of all the shipped products (shipment by pipeline, road, rail and water transport, as well as in other containers with small packaging);
\[ \sum M'_{toll} \] is mass of raw material, components and petroleum products losses on all of the production, storage and shipment stages.

In (2) \[ \sum M_{en} \] and \[ \sum M_{prod} \] are usually set accurately without error. This is due to the fact that these values are taken into account from “documented sources”: acts of acceptance of raw materials and acts of shipment of products. Although these documents, of course, indicate the method by which measurements were made, these values are applied exactly to reduce the material balance. Adjustments within the error of the methods or measuring instruments with which these values are obtained are not made. Accounting for the error of \[ \sum M_{en} \] and \[ \sum M_{prod} \] in production accounting and in the material balance is an interesting topic that deserves separate consideration.

Accordingly, the process of material balance reduction is in manipulating the primary production data within the values of \[ \Delta M'_{rest} \] and \[ \sum M_{toll} \] from (1) and turning them into \[ \Delta M'_{rest} \] and \[ \sum M'_{toll} \] from (2).

The value of the losses \[ \sum M_{toll} \] in the initial approximation can be considered as a certain amount of raw materials, components and petroleum products lost during the production, storage and movement of petroleum products. Physical losses occur due to equipment and pipelines leaks, features of technological processes, design features of equipment and tanks, theft, accidents, evaporation, respiration, and so on. Losses can be returnable or non-returnable, identifiable or unidentifiable, controlled or uncontrollable, natural or due to a particular technological process or design solution, stable or transient operation of a technological facility, and so on.

Usually, production losses are determined by the loss coefficient at a specific production stage. So for a technological facility, the value of losses is determined on the basis of design data, and for other production sites it is determined by specialized organizations on the basis of federal legislation, for example, Order No. 364 of the Ministry of Energy of Russia of 13.08.2009 "On approval of standards for natural loss of oil products during storage" [16].

\[ \sum M'_{toll} = \sum (K_{toll_i} \cdot M_{ref_i}) + \sum M_{man} \], \hspace{1cm} (3)

where:
\[ K_{toll_i} \] is loss coefficient for each processed, moved or stored ton of product at a specific production site or production facility;
\[ M_{ref_i} \] is total mass of processed, moved or stored raw materials at a specific production site or production facility;
\[ \sum M_{man} \] is total mass of production losses.

Production losses, generally, arise due to the need to change the operating modes of production facilities, or to change the movement routes of petroleum products, for example, dismantling the pipeline, cleaning the tank, preparing the process unit for repair – in all these cases it is impossible to completely remove the oil product and engage it in production.

Of course, the normalization method cannot take into account the actual losses at each time point. It is in normalization nature to exaggerate losses considering all of the possible situations. Therefore, in phase of stable production the value of \[ \sum (K_{toll_i} \cdot M_{ref_i}) \] (from (3)) significantly exceeds the value of actual losses. This can be expressed in the following equation:

\[ \sum (K_{toll_i} \cdot M_{ref_i}) = \sum M_{fact_i} + R \], \hspace{1cm} (4)
where:

\[ \sum M_{\text{fact}.i} \] is an actual losses of oil products at specific production site or technological facility;

\[ R \] is the value showing (compensating) the difference between the normative and actual losses.

The value \( \sum M_{\text{fact}.i} \) usually cannot be measured but it can be calculated for a specific production site or technological object in a specific period of time using the formula similar to (2). In the case of a stable operation mode of the object \( \Delta M_{\text{rest}} \) can be neglected. The formula will look like:

\[ \sum M_{\text{en}} - \sum M_{\text{prod}} = \sum M_{\text{fact}}. \] (5)

That is the value \( \sum (K_{\text{tol}.i} \cdot M_{\text{ref}.i}) \) from (3) depends only on total processing mass, and \( \sum M_{\text{fact}} \) depends on quality of technological process at the specific period of time.

In practice, to reduce material balance the value \( \sum (K_{\text{tol}.i} \cdot M_{\text{ref}.i}) \) is used. The value \( R \) is used for adjustment of primary production data during manipulations.

Consider value \( \sum M_{\text{ref}.} \). It is usually determined either indirectly or on the basis of expert review. The value of losses in an indirect assessment is often underestimated, while with expert evaluation it is overestimated. So, for example, if we indirectly estimate the remains in the pipeline after such an operation as pumping the pipeline, then it can be assumed that there is no oil product residue in the pipeline. This will lead to the fact that a certain amount of oil will be removed during steaming of the pipeline, irretrievably lost and not counted. If in the same situation an expert assessment is applied, then it is likely that the value of these irretrievable losses will be determined in such a way that the total losses of the given technological object for given time period will be close to zero.

The residues delta \( \Delta M_{\text{rest}} \) is the most accessible value for rechecking and auditing. However it is the most manipulated value in term of material balance reducing. The residues delta is determined by the following expression:

\[ \Delta M_{\text{rest}} = \sum M_{\text{rest}.\text{start}.\text{stage}} - \sum M_{\text{rest}.\text{end}.\text{stage}}, \] (6)

where:

\[ \sum M_{\text{rest}.\text{start}.\text{stage}} \] is the actual amount of all raw materials, components and products at the beginning of the considered period;

\[ \sum M_{\text{rest}.\text{end}.\text{stage}} \] is actual quantity of raw materials, components and products at the end of the considered period.

The value of \( \sum M_{\text{rest}.\text{start}.\text{stage}} \) is recorded at the beginning of considered period. The value of \( \sum M_{\text{rest}.\text{end}.\text{stage}} \) is obtained based on the residues measurement at the end of the considered period of time. This value is fixed after results of other data analysis are received (in essence, the corrected data is recorded for the needs of the material balance). Correction of any of the addendums \( M_{\text{rest}.\text{end}.\text{stage}.i} \) composing \( \sum M_{\text{rest}.\text{end}.\text{stage}} \) can lead to deformation of material balance of specified i-th production facility. In other words it leads to imbalance. For this, one more type of manipulation is used – transfer of imbalance. The value of the imbalance obtained in the considered period can be reduced, for example, by half, and the remaining half can be transferred to the next period.

In turn, there is a procedure for the final evaluation of the data obtained as a result of the balance reduction, and the data of the primary production accounting. This procedure is called inventory and it is intended just for finding the actual value of residues in tank parks [10-16]. But this procedure is quite rare (as a rule, it is planned to be carried out once a month), and therefore, manipulations remain possible within a month, and adjustments are brought to zero within the limits of the monthly interval.

The difference between inventory data and balance reduction data is called excess loss or deficiency.

The material balance of a technological object is formed based on the (1). In case of technological facility sufficiently equipped with measuring devices it is obtained on the basis of primary production
data and is not a subject for adjustment. This is also due to the fact that there is APCS at technological facilities in which the balance data is recorded, and, consequently, audited. The criterion for the accuracy of the production accounting of the material balance of a technological facility is the value of $N$ from (1), that is, the amount of deviations (at maximum losses within normal limits), which is caused by the total error of measuring devices.

In case of CP, the material balance is also formed on the basis of (1), but experience shows that the technical equipping of CP with measuring instruments does not allow calculating the mass in the automatic mode, therefore manual measurement and/or manual mass calculation are used, which also results to the possibility of manipulation. The criterion for the accuracy of production accounting material balance of CP is the value of $N$ from (1), that is, the value of the deviations (at maximum losses within normal limits), which is caused by the total error of metering devices. The value of the deviations of actual residues in CP (inventory results) from data of the material balance is also can serve as a criterion for CP.

The greatest interest in terms of manipulation has a production operation for the movement of a batch of petroleum products as an element of accounting, in which manipulations should be excluded.

3. Formulation of the problem

The purpose of this work is to develop an approach to ensure the accuracy of accounting at a modern refinery.

Objectives of the research:
1. To analyze the existing problems in the production accounting and material balance (presented in Section II. Current problem state of this work).
2. To analyze the applied methodology for the formation of the material balance of technological refinery objects, such as technological facilities and CP (presented in Section II. Current problem state of this work).
3. Justify the criterion of admissible deviations for the production operation of moving the oil product batch during production accounting.

The criterion of admissible deviations. In general, for real oil refining production (oil storage facilities) in real conditions, the admissible deviation is the difference in determining the value of the moved oil product batch measured at the source object (several source objects) or receiver object (several receiver objects) that does not cause suspicion the security service or operating personnel in the possible theft of petroleum products. In other words, if it is clearly seen that during the transfer of petroleum products a significant amount was lost – you need to gather a commission and determine where the petroleum product has gone.

If we are talking about a systematic deviation "in one direction" of the results of mass determination at the source and the receiver objects for a long time, it is required to identify the frequency of occurrence of such deviation (is it there and why), to carry out a statistical analysis of deviations and its causes, for example: unauthorized switching of pipelines, unaccounted losses, leakage of pipelines, incorrect operation of measuring devices (MD). For a sufficiently long period of time (from several days to one month), the occurrence of deviations in determining the mass is possible, but their sum should be about zero tons. This is observed, if deviations arise, then in one, then in the other direction. With a systematic deviation, the sum of the deviations is a certain value. The presence of such value (at the same time, it should be of interest for potential intruders in monetary terms) is a criterion for permissible deviations.

It is noteworthy that if the receiving object systematically receives a greater amount of oil than the source object gives, this, in addition to other factors, such as malfunctioning of measuring devices and automation (MDaA) or leakage of pipeline fittings, also does not exclude the possibility of theft, since it may be advantageous for attackers to create uncertainty in one section of the production chain, and steal oil products at another.

Systematic deviations (imbalances), usually, are specific to production chains of several objects (primary processing facility – intermediate CP – secondary processing facility – intermediate CP –
installation or CP of commodity product preparation – commodity CP) and represent the primary information for determining the object (CP, technological facility or pipeline section), on which there is an incorrect accounting of petroleum products.

As mentioned above, the balance, and, consequently, the identification of systematic or periodic deviations in accounting at technological facilities, with the current level of technical equipment, is characterized by the presence and accuracy of setting up MDaA tools. If there are no flow metering devices on any flows of the technological facility, they are formed on the basis of indirect data, for example, with the help of counting on associated facilities, and, as a rule, this is the CP.

In the CP, accounting should be considered as a set of separate operations, each of them should be a unit of accounting information, and the final values should be formed over a long period based on the processing of these operations. It is very important to be able, in terms of aggregated data, to determine which operations led to a distortion of the total value. Analysis of data on this operation, such as: at what time, by whom the operation was performed, what technological mode was at the facility at that time, what operations were carried out in parallel or in conjunction with this operation, will allow to identify sources of data distortion, as well as to determine the deviation value and its effect on the final imbalance. This value should also be compared with the criterion of admissible deviations, only in contrast to the analysis of the production chain, in such a case it becomes possible to carry out control for each operation for the movement (storage) of the oil product. Deviations in the movement of the mass of petroleum products in a single production operation are easily detectable with transparent accounting, and are difficult to detect with the current accounting method.

4. The choice of the criterion of admissible deviations taking into account the movement of oil products batch

The criterion of admissible deviations (CAD) for two accounting positions can be determined in five ways:

\[
\Delta M_{\Sigma} = 1.1 \cdot \sqrt{(M_1 \cdot \delta M_1)^2 + (M_2 \cdot \delta M_2)^2},
\]

\[
\Delta M_{\Sigma} = \sqrt{(M_1 \cdot \delta M_1)^2 + (M_2 \cdot \delta M_2)^2},
\]

\[
\Delta M_{\Sigma} = \min(\delta M_1; \delta M_2) \cdot M_{\text{ave}},
\]

\[
\Delta M_{\Sigma} = \max(\delta M_1; \delta M_2) \cdot M_{\text{ave}},
\]

\[
\Delta M_{\Sigma} = \text{case}(\delta M) \cdot M_{\text{ave}},
\]

where:

\(\Delta M_{\Sigma}\) – is CAD value (tons);

\(M_1\) – the mass of oil products (tons) recorded by the first accounting position (for example, at the source facility from which a batch of oil product is being pumped);

\(M_2\) – the mass of oil products (tons), recorded at the second accounting position (for example, at the receiving facility, where the batch of oil products is being pumped);

\(\delta M_1\) – error (%) of the first accounting position;

\(\delta M_2\) – error (%) of the second accounting position;

\(\text{case}(\delta M)\) – some error (%) determined by the person who formulated the approach to accounting;

\(M_{\text{ave}}\) – average mass (tons) recorded by a pair of accounting positions.

Justification of the choice of CAD options when moving a batch of oil products, recorded by a pair of meters:

Option 1 (7) - this option is justified from the point of view of metrology and represents the root-mean-square estimate of the deviation, taking into account the probabilistic assessment of the accuracy
of the application of the mass measurement method (with a probability of 0.95, the Student's coefficient is 1.1 according to GOST 8.736-2011). This option is recommended by the author for practical application, if one or both of the metering positions are tanks when moving a batch of oil products, and manual mass measurement is used.

Option 2 (8) - this option is justified from the point of view of metrology and represents the root-mean-square estimate of the deviation, taking into account the probabilistic assessment of the accuracy of applying the method of mass measurement (with a probability of 0.99, the Student's coefficient is 1 according to GOST R 8.736-2011). This option is recommended by the author for use in practice if, when moving a batch of oil product, both metering positions are automated measurement tools, for example, mass meters or metering units.

Option 3 (9). The use of this option can be justified by the fact that the transfer of a batch of petroleum products is not always associated with a change in the area of responsibility. In this case, it is appropriate to use the data of the mass meter as the maximum possible deviation during the transfer from the facility to the tank through the mass meter. It has a lower (minimum) error compared to manual or automated determination of the mass in the tank.

Option 4 (10). The use of this option can be justified by the fact that measuring by tanks is administratively executed as the main accounting scheme, measuring by metering station (mass meters) as a backup. This approach can follow from multipurpose designation of the pipeline on which the mass meter is installed (for example, additive intake and circulation along the same line). In such situation, the uniqueness of flow directions can be guaranteed only by taking additional measurements, such as a re-commissioning of pipeline valves and its sealing. It is clear that during operational work such activities are not carried out, therefore, they use metering by tanks as the main accounting scheme.

Option 5 (11). This option can be used as an additional guarantee of the accuracy of measuring the mass of the cargo for the sending enterprise. So, the accuracy of the method for determining the mass in railway tanks is 0.65% (an indirect method of static measurements), and when shipped, operating personnel can use the value of 0.56% as CAD, which increases the probability of fitting into the error of 0.65% when measuring on the customer's side.

Of course, all the above described CAD options should be implemented in software products for mass calculating and be applied to each mass movement operation. It is important to note that option 1 is the most universal and applicable for a wider range of tasks than others. The most important decision for today for our enterprises is the very fact of introducing such tools for each operation while keeping track of both technological, production and storage facilities.

5. Conclusion
The relevance of the issue of obtaining an authentic material balance is due to the fact that many important conclusions can be drawn and operational management decisions can be made on its basis. Detailing the process of obtaining this balance to the level of a specific production operation allows us to provide with such a tool (reliable information about the operation) those specialists of the enterprise who do not make decisions for the whole enterprise, but producing their actions, participate in shaping the balance of the enterprise. The final goal of the organization of reliable operational accounting is to approximate its results to the data, which is obtained as a result of reducing the material balance [17-18]. Ideally, reliable production accounting should completely replace the material balance reduction process.

Operational analysis of the quality of production accounting for each operation that uses the criterion given in this article can be integrated into the processes of mass measuring and calculating at the existing level of production automation, as well as influencing decision making at the first level of obtaining information – the level of collecting primary production data.

Improving the reliability of the results of each operation leads to a decrease in the total imbalance over the entire production facility, makes the problems of deviations in the received data understandable and allows you to remove most of them at the time of actual detection or at the nearest
scheduled repair of the facility. The total material balance of the enterprise is formed on the basis of
the material balances of the objects. Its reduction affects the efficiency of the entire production and
leads to an increase in the depth of oil refining and to decreasing of losses.

The choice of the mathematical model of the criterion of admissible deviations in this article is
based on its transparency and informativeness for the operational staff. The approaches described for
the definition of this criterion, but not outlined as optimal, can and should be applied in different
production situations, but most likely less often than the chosen criterion. A significant result of the
research is the substantiation of the need for a fundamental decision on the application of the specified
criterion in production when moving and storing petroleum products [7, 19, 20]. This point should be
transparent and documented. Any uncertainty in the regulation of activities related to material values
(which is the oil product) can be used to cover unidentified losses.

This approach greatly simplifies the organization of accounting and allows you to quickly identify
discrepancies in data when moving mass and to take measures to eliminate defects in the accounting.
Thus, it allows you to identify specific stages of production at which imbalance appeared.

The above-mentioned defects in the accounting of petroleum products on the scale of an average
Russian refinery with productivity about 6 million tons per year can significantly distort the
assessment of the true production losses. For example, the existing method of accounting may “lose”
for the year the amount of petroleum product (gasoline), comparable to the contents of a full tank of
finished petroleum product with a capacity of 5000 cubic meters.

The solutions proposed by the authors for the production accounting procedure make it possible to
increase its reliability and abandon the process of the material balance reduction.

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