Determining the location of the well's production collecting site at an oil field

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Abstract. The paper considers a possible solution to the problem of optimizing the location of a well’s production collecting site at an oil field. Depending on the location of the collecting site, the length of the pipelines going from the well clusters changes. Minimizing the total length of the oil collecting pipelines network will lead to lower capital costs for the construction of a well’s production collection system.

1. Introduction

When designing a well’s production collection system at an oil field, the question of choosing the optimal location for the well’s production collecting site arises.

Well clusters are connected by pipelines to the collecting site. Depending on the location of this site, the length of pipelines going from well clusters will vary. Pipelines can also have different diameters, depending on the capacity of the well. Reducing the total length of these pipelines leads to lower capital costs for their construction.

Determining the location of the well’s production collecting site at which the cost of constructing a pipeline network will be minimal taking into account the different diameters of the sections is an urgent optimization problem.

2. Materials and methods

Consider the case of determining the location of the well’s production collecting site from N wells on flat terrain. Let the well clusters be located at points with coordinates \((x_i, y_i)\), the desired optimal coordinates of the collecting site location will be denoted by \((x, y)\). All well clusters are connected to the production collecting site by pipelines (Figure 1).

![Figure 1. Schematic diagram of the pipeline network from well clusters to the production collecting site](image-url)
Since the diameters of these pipelines depend on the capacity of the wells and can be different, we assign to each pipeline a weight \( w_i \) that characterizes the relative unit cost of the pipeline section construction:

\[
    w_i = \frac{C_i}{C_0}
\]  

(1)

where \( C_i \) – unit cost of the i-th section of the pipeline construction;
\( C_0 \) – unit cost of the reference section of the pipeline construction.

We take the cost of constructing a network of pipelines from well clusters to the production collecting site as the optimization function, which can be determined by the formula [7]:

\[
    C = C_0 \sum_{i=1}^{N} w_i \sqrt{(x - x_i)^2 + (y - y_i)^2}
\]

(2)

where \( x_i, y_i \) – i-th well cluster coordinates;
\( x, y \) – production collecting site coordinates;
\( w_i \) – weight of the pipeline from the i-th well cluster.

We’ll find the minimum of this function using the Newton method [1-4]. To do this, we need to set arbitrary initial coordinates \((x_k, y_k)\) from which we will start the search. For example, it can be taken as the arithmetic mean value of the well clusters coordinates:

\[
    x_k = \frac{\sum_{i=1}^{N} x_i}{N}; \quad y_k = \frac{\sum_{i=1}^{N} y_i}{N}
\]

(3)

Find the gradient of the cost function:

\[
    \nabla C = \begin{bmatrix} \frac{\partial C}{\partial x} \\ \frac{\partial C}{\partial y} \end{bmatrix} = \begin{bmatrix} \frac{C_0}{\sqrt{(x - x_i)^2 + (y - y_i)^2}} \\ \frac{C_0}{\sqrt{(x - x_i)^2 + (y - y_i)^2}} \end{bmatrix} \sum_{i=1}^{N} w_i
\]

(4)

Calculate the value of the cost function gradient at the point \((x_k, y_k)\):

\[
    \nabla C(x_k,y_k) = \begin{bmatrix} \frac{C_0}{\sqrt{(x_k - x_i)^2 + (y_k - y_i)^2}} \\ \frac{C_0}{\sqrt{(x_k - x_i)^2 + (y_k - y_i)^2}} \end{bmatrix} \sum_{i=1}^{N} w_i
\]

(5)

Find the absolute value of the gradient at the point \((x_k, y_k)\):

\[
    |\nabla C(x_k,y_k)| = C_0 \sqrt{\left( \sum_{i=1}^{N} \frac{w_i}{\sqrt{(x_k - x_i)^2 + (y_k - y_i)^2}} \right)^2 + \left( \sum_{i=1}^{N} \frac{w_i}{\sqrt{(x_k - x_i)^2 + (y_k - y_i)^2}} \right)^2}
\]

(6)

Next, check the condition for finding the minimum of the cost function with a given accuracy:

\[
    |\nabla C(x_k,y_k)| < \delta
\]

(7)

where \( \delta \) – required accuracy for finding the minimum of the function.

If condition (7) is satisfied, then we can assume that the optimal location coordinates of the well’s production collecting site are found with a given accuracy \( \delta [5-7] \);
\[ x = x_k, \quad y = y_k \]  \hspace{1cm} (8)

If condition (7) is not satisfied, then we need to find the inverted Hessian matrix at the point \((x_k, y_k)\):

\[ H = \begin{bmatrix}
\frac{\partial^2 C(x_k, y_k)}{\partial x^2} & \frac{\partial^2 C(x_k, y_k)}{\partial x \partial y} \\
\frac{\partial^2 C(x_k, y_k)}{\partial y \partial x} & \frac{\partial^2 C(x_k, y_k)}{\partial y^2}
\end{bmatrix} \hspace{1cm} (9) \]

where

\[ \frac{\partial^2 C(x_k, y_k)}{\partial x^2} = C_0 \sum_{i=1}^{N} w_i \left( \frac{- (y_k - y_i)^2}{\sqrt{(x_k - x_i)^2 + (y_k - y_i)^2}} - 1 \right) \right) \]

\[ \frac{\partial^2 C(x_k, y_k)}{\partial y^2} = C_0 \sum_{i=1}^{N} w_i \left( \frac{- (x_k - x_i)^2}{\sqrt{(x_k - x_i)^2 + (y_k - y_i)^2}} + 1 \right) \]

\[ \frac{\partial^2 C(x_k, y_k)}{\partial x \partial y} = C_0 \sum_{i=1}^{N} w_i \left( \frac{- (x_k - x_i)(y_k - y_i)}{(x_k - x_i)^2 + (y_k - y_i)^2} \right) \]

Inverted Hessian matrix:

\[ H^{-1}(x_k, y_k) = \frac{1}{\frac{\partial^2 C(x_k, y_k)}{\partial x^2} \frac{\partial^2 C(x_k, y_k)}{\partial y^2} - \left( \frac{\partial^2 C(x_k, y_k)}{\partial x \partial y} \right)^2} \begin{bmatrix}
\frac{\partial^2 C(x_k, y_k)}{\partial x^2} & -\frac{\partial^2 C(x_k, y_k)}{\partial x \partial y} \\
-\frac{\partial^2 C(x_k, y_k)}{\partial y \partial x} & \frac{\partial^2 C(x_k, y_k)}{\partial y^2}
\end{bmatrix} \hspace{1cm} (11) \]

Using the recurrence formula, we calculate the coordinates of the desired point in the next step:

\[ \begin{bmatrix}
\frac{x_{k+1}}{y_{k+1}} = \frac{\frac{x_k}{y_k} - \frac{1}{H(x_k, y_k)} \cdot \nabla C(x_k, y_k)}{y_{k+1}} \end{bmatrix} \hspace{1cm} (12) \]

Substitute (4), (10) into (11):

\[ \begin{bmatrix}
\frac{x_{k+1}}{y_{k+1}} = \frac{\frac{x_k}{y_k} - \frac{1}{\frac{\partial^2 C(x_k, y_k)}{\partial x \partial y} \frac{\partial^2 C(x_k, y_k)}{\partial y^2} - \left( \frac{\partial^2 C(x_k, y_k)}{\partial x \partial y} \right)^2} - \frac{\partial^2 C(x_k, y_k)}{\partial x \partial y}}{\frac{\partial^2 C(x_k, y_k)}{\partial y \partial x} - \frac{\partial^2 C(x_k, y_k)}{\partial x \partial y}} \\
\frac{x_{k+1}}{y_{k+1}} = \frac{\frac{x_k}{y_k} - \frac{1}{\frac{\partial^2 C(x_k, y_k)}{\partial x^2} - \frac{\partial^2 C(x_k, y_k)}{\partial x \partial y} \frac{\partial^2 C(x_k, y_k)}{\partial y^2} - \left( \frac{\partial^2 C(x_k, y_k)}{\partial x \partial y} \right)^2} - \frac{\partial^2 C(x_k, y_k)}{\partial y \partial x}}{\frac{\partial^2 C(x_k, y_k)}{\partial x \partial y} - \frac{\partial^2 C(x_k, y_k)}{\partial y^2}} \\
\frac{x_{k+1}}{y_{k+1}} = \frac{\frac{x_k}{y_k} - \frac{1}{\frac{\partial^2 C(x_k, y_k)}{\partial x \partial y} \frac{\partial^2 C(x_k, y_k)}{\partial y^2} - \left( \frac{\partial^2 C(x_k, y_k)}{\partial x \partial y} \right)^2} - \frac{\partial^2 C(x_k, y_k)}{\partial x^2} \frac{\partial^2 C(x_k, y_k)}{\partial y^2} - \left( \frac{\partial^2 C(x_k, y_k)}{\partial x \partial y} \right)^2} - \frac{\partial^2 C(x_k, y_k)}{\partial y \partial x}}{\frac{\partial^2 C(x_k, y_k)}{\partial x \partial y} - \frac{\partial^2 C(x_k, y_k)}{\partial y^2}} \end{bmatrix} \hspace{1cm} (13) \]

Calculations according to formulas (5) – (13) are repeated until the condition (7) is satisfied. The above calculations can be represented as an algorithm (Figure 2) [8-11].
Figure 2. Algorithm of finding the well’s production collecting site optimal location.

3. Conclusion
The cost of a pipeline laying depends not only on its length and diameter. There are other factors that are not taken into account in this method. For example, the technique of laying the pipeline, the amount of equipment involved, etc., depends on the terrain and the geological conditions. As a result, this also affects the unit cost of the pipeline laying.

Thus, the presented method allows us to find the optimal location of the well’s production collecting site at the oil field with a given accuracy in the conditions of a flat terrain within the considered area.

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