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# Research on Garment Washing Optimization Based on Linear Programming and Iterative Algorithm

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**Abstract:** This study is dedicated to exploring the optimization strategies for impurity dissolution during garment washing, aiming at minimizing the number of washes and water costs, while ensuring that the clothes are cleaned as expected. The proposed model was evaluated in a series of programming simulation experiments to obtain optimal solutions for several key problems. The study first applies an iterative algorithm to achieve the optimal rationing of the amount of washing and water consumption under specific conditions. Then, the variables were dynamically combined and resolved to deeply analyze the effects of initial solubility, decay coefficient, and initial contamination on the results. Finally, a mathematical model for detergent selection was developed through a linear programming model, which resulted in the optimal selection and lowest cost of different detergents based on the constraints and objective function.

**Keywords:** Washing Optimization; Contaminant Dissolution; Iterative Algorithms; Linear Programming Models.

## 1. Introduction

Laundry practices have evolved since ancient times, with current techniques focusing on maximizing efficiency and quality. The effectiveness of modern laundry detergents is attributed to surfactants, which possess dual functionalities. One end of the surfactant molecule is lipophilic, attracting dirt and repelling water, while the other end is hydrophilic, drawing water molecules. This structure allows surfactants to decrease water's surface tension, facilitating the penetration of water molecules between dirt particles and surfaces, and enabling effective cleaning. However, challenges remain in optimizing the relationship between water usage, detergent efficiency, and cleaning outcomes. This paper addresses these challenges through three distinct tasks. The first task seeks to determine the optimal balance between the number of washes and water consumption for effective dirt removal, considering dirt's solubility in water. The second task aims to devise the most time-efficient cleaning method, ensuring that the final dirt residue is minimal, while the third task focuses on identifying the most cost-effective and efficient cleaning solution, considering various detergent types and their prices. By addressing these problems, this study contributes to enhancing the efficiency and effectiveness of laundry practices. [1]

## 2. Optimizing Washing Times and Water Consumption through Iterative Algorithms

### 2.1. Modeling

Assuming that the initial fouling amount and available water amount are $D_0$ and $W$, respectively, it has been clearly stated in question that only traditional water washing methods are considered, so the detergent is water. As discussed earlier, increasing the amount of water used for each wash has an extremely limited impact on the washing effect and is not the best washing method. Therefore, we use a fixed amount of water used for each wash to reach the minimum water consumption for solubility $a_k$, and we simply set it two.

Secondly, we assume that the washing frequency is $k$, and the amount of dirt after the $k$-th washing is $D_k$. It is not difficult to produce:

$$D_K = D_{z-1} - \mathrm{w_k} a_\mathrm{k} D_\mathrm{u} \tag{1}$$

$$a_k = \frac{a_{k-1}}{2} \tag{2}$$

Combining (1) and (2), we can obtain the expression for $D_k$ as follows:

$$D_k = D_0 \prod_{i=1}^{k} \left(1 - \frac{a_1}{2^{i-1}}\right) \tag{3}$$

The trend curve of $D_k$ drawn at this time is shown in Fig. 1:

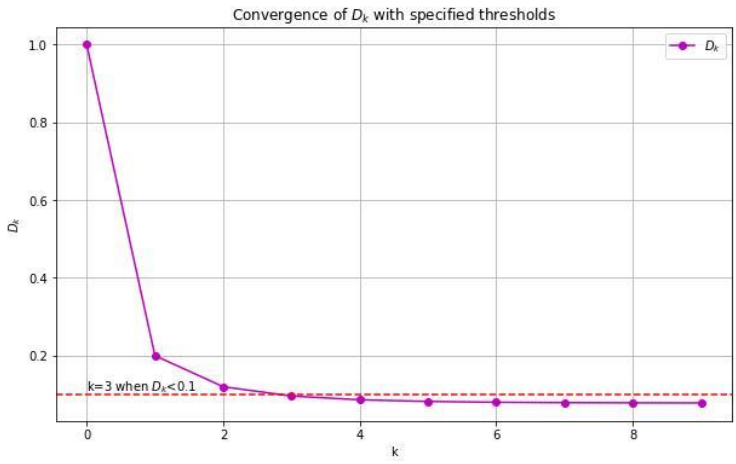



**Fig. 1** Trend Curve of $D_k$

According to the graph, as the number of washes increases, the remaining amount of dirt gradually approaches a certain value, converging to 0.08, which means that the remaining dirt is 8% of the original amount. If this method of washing is used, assuming that there is sufficient water, washing three to four times would reduce the amount of dirt to around 10%. There is a significant decrease in dirt during the fourth wash. If washed again, the effect of removing the dirt would weaken, so multiple washes are not recommended. Therefore, the optimal number of washes is 3-4 times, and the amount of water used each time should be the minimum amount that satisfies the solubility.

## 2.2. Solution of the model

Here, the effects of $a_k$, the amount of initial fouling, and the availability of water on the target are discussed as described above. Here we change $a_k$ and look at the changes in the curve in Fig. 1, taking 0.6 and 0.9 respectively. The results are as follows in Fig. 2 and 3:

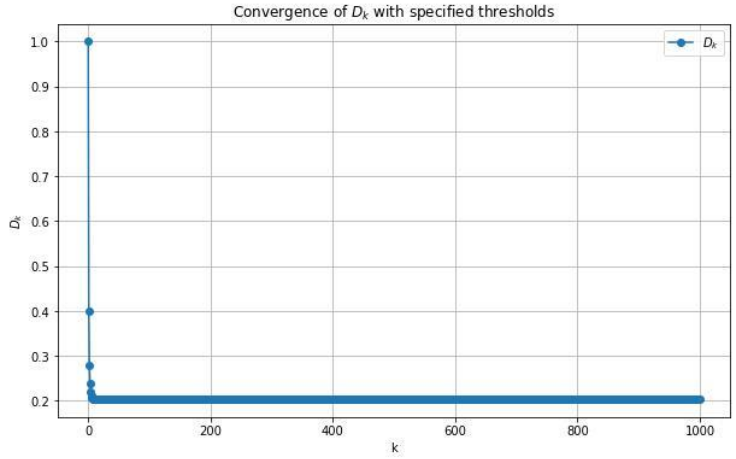



**Fig. 2** The trend curve of $D_k$ at $a_k = 0.6$

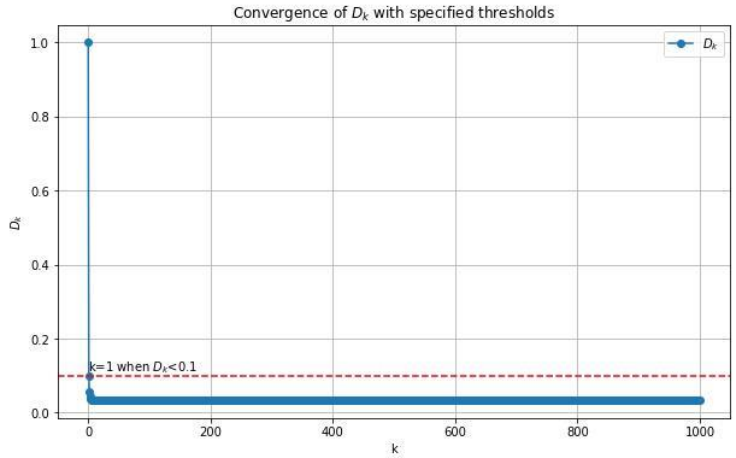



**Fig. 3** The trend curve of $D_k$ at $a_k = 0.9$

When $a_k$ is taken as 0.6, $D_k$ converges to around 0.2, and when $a_k$ is taken as 0.9, $D_k$ converges to around 0.03.

The findings indicate that an increase in $a_k$ notably enhances the washing effect. Additionally, the research

examines the relationship between initial dirt levels and available water volume. In scenarios where water is scarce or the initial dirt quantity is substantial, the approach entails maintaining a consistent unit water volume for each wash until depletion. Conversely, when sufficient water is available relative to the initial dirt amount, the number of laundry cycles can be strategically chosen based on the $D_k$ curve. This analysis underscores the importance of considering both the attenuation coefficient and initial washing conditions to optimize the cleaning process [2].

# 3. Dynamic Analysis of Solubility and Attenuation Coefficients in Cleaning Efficiency

## 3.1. Modeling

This research examines two distinct cases to optimize laundry efficiency. In the first case, the study considers the dissolution effect of water in a single wash, hypothesizing a direct proportionality between this effect and the unit water volume. Under this assumption, achieving the desired cleaning effect—reducing the dirt to less than one-thousandth of its initial amount—requires only a single wash. The water consumption for this process is quantified by the formula $w = (1 - 1/1000)/a_k$, representing a timely solution with minimal cleaning cycles.

The second case builds upon the premise established in the first scenario, with specific parameters $a_0 = 0.8$ and $a_k = 0.5a_k - 1$. Analysis indicates that multiple washes under these conditions can only limit the residual dirt to approximately 8%. To enhance efficiency, the study suggests adjusting the ratio of $a_0$ and the decrease in the washing effect. By assuming the solubility of the first wash as $a_0$ and $a_k = ma_k - 1$, the research explores various combinations of $a_0$ and $m$ through programming. This approach aims to identify a strategy that minimizes the number of washes while achieving a residual dirt amount of one-thousandth. This case emphasizes the need for a tailored approach, combining empirical analysis and computational methods to optimize the laundry process.

## 3.2. Solution of the model

1) If we limit the values of $a_0$ and $m$ to (0,1), we can make them traverse the search graph as follows in Fig. 4:

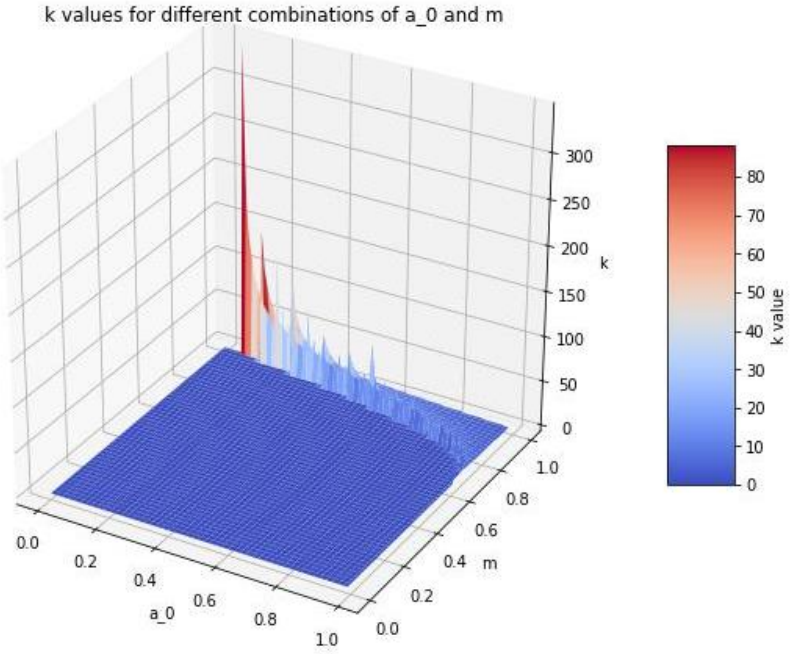



**Fig. 4** Values of $k$ for different combinations of $a_0$ and $m$. (0,1)

Upon observation, if $m$ is large enough and $a_0$ is greater than 0.06, after multiple washes, the remaining amount of dirt can always be reduced to less than one-thousandth. The maximum number of washes is approximately eighty. However, the minimum value of $m$ should also be 0.62 or higher. Otherwise, to reduce the amount of dirt to one-thousandth, when $a_0$ is 0.98 and $m$ is 0.97, $k$, which represents the number of washes, will be at its smallest, at a value of 2. That is, washing twice can reduce the dirt to one-thousandth of its original amount.

2) If we limit the range of $a_0$ and $m$ to (0.5, 0.9), the two-dimensional and three-dimensional graphs used for traversal are as follows in Fig. 5:

After observation, only when $a_0$ is greater than 0.6 and $m$ is greater than 0.8, can the dirt be washed to one thousandth, with a maximum of thirty-four times to be washed. At this time, when $a_0 = 0.86$ and $m = 0.89$, the washing frequency is the least, with a value of 6, which means that the clothes can be completely washed at most 6 times. The influence of the $a_k$ and initial fouling amount on the scheme.

In this study, two key factors influencing the laundry optimization plan are analyzed. The first factor is the attenuation coefficient ($a_k$). It is found that both the initial solubility of the dirt and its rate of decay significantly affect the cleaning process. These elements are crucial in determining the effectiveness of the washing and must be carefully balanced to achieve optimal results. The second factor examined is the impact of the initial amount of dirt. The research indicates that dirt, which is easily removable, does not significantly alter the solution, primarily because the initial amount of dirt does not drastically change water usage, especially when water is not a limiting factor. This suggests that in scenarios with ample water availability, the amount of water used for each wash is not significantly impacted by the

initial dirt level. These insights highlight the importance of considering both the chemical properties of dirt and the available resources to develop efficient and effective laundry strategies [3].

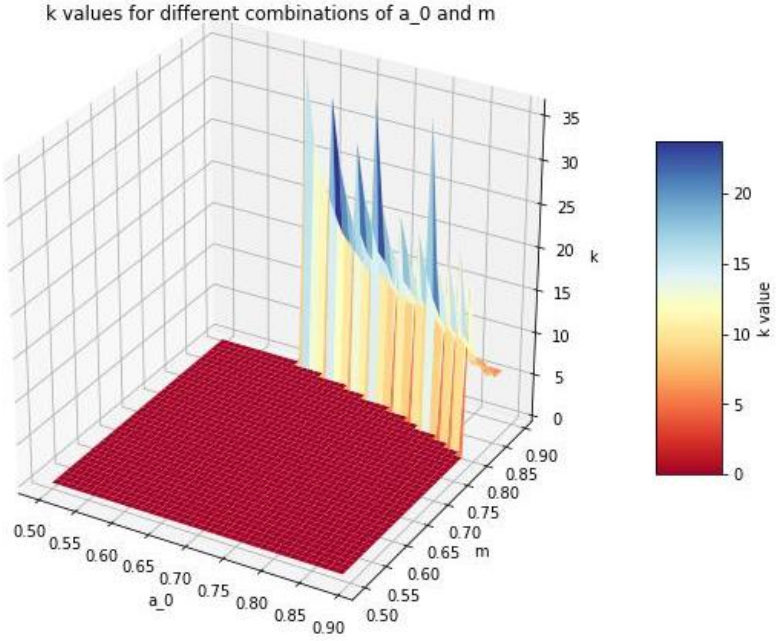



**Fig. 5** Values of $k$ for different combinations of $a_0$ and $m$. (0.5,0.9)

# 4. Cost-Effective Detergent Selection Using Linear Programming Models

## 4.1. Modeling

This research addresses the challenge of selecting detergents to balance cost and cleaning effectiveness, employing a mathematical model for resolution. The model is structured around an objective function and constraints. The objective function aims to minimize the total cost, which comprises the costs of various detergents and water. The constraints include a dirt dissolution constraint, ensuring sufficient detergent quantities to dissolve each pollutant, and a non-negative constraint on detergent quantity, ensuring selected detergent amounts are not negative [4].

The model is a linear programming problem, formulated as follows: The objective is to minimize the sum of the products of detergent prices and quantities, plus water expenses. The dirt dissolution constraint ensures the combined detergent quantities are adequate for dissolving the specified amounts of each pollutant. The non-negative constraint ensures the selected detergent quantities are not negative. This model can be solved using linear programming or other optimization techniques. Data from relevant tables and factors such as water costs are incorporated into the model, which is then solved using software tools like the Pulp library in Python or MATLAB's optimization toolbox [5].

$$Minimize: \sum_{i=1}^{10} P_i \cdot C_i + E_{\text{water}} \tag{4}$$

However, the model requires refinement to account for additional details and variables. One such consideration is the fixed cost of water, highlighting the need to examine the complex interplay between pollutant solubility and detergent effectiveness. These enhancements are crucial for improving the model's accuracy and applicability in real-world scenarios.

## 4.2. Solution of the model

This Fig. 6 shows the number of various pollutants on diverse types of clothing. The horizontal axis represents diverse types of pollutants, the vertical axis represents the quantity of pollutants, and each bar chart represents a type of clothing. Through this image, the distribution of different pollutants on different clothing types can be compared, the differences in pollutants between different clothing types can be analyzed, and the distribution of diverse types of pollutants in various clothing types can be understood. This visualization helps to quickly compare the distribution of pollutants on different clothing types and is extremely helpful for analyzing the characteristics of pollutants and the differences in clothing types. This visualization helps to quickly compare the distribution of pollutants on different clothing types and is extremely helpful for analyzing the characteristics of pollutants and the differences in clothing types.

This Fig. 7 shows the washing effects of different detergents on various pollutants. The horizontal axis represents diverse types of pollutants, while the vertical axis represents a measure of washing effectiveness. Through this image, we can compare the cleaning effects of different detergents on pollutants, analyze the impact of detergents on different pollutants, and understand the distribution of cleaning effects of diverse types of pollutants in various detergents. This graph can help understand the performance of different cleaning agents when cleaning different pollutants and select the most suitable cleaning agent for cleaning specific types of pollutants.

This Fig. 8, "Total Pollutants Except Detergent" shows the proportion of total pollutants other than detergents. Similarly, different sectors represent different pollutant types, and the size of the sector indicates the proportion of the pollutant in the total pollutant, and the percentage of each is shown by the

numerical label. The relative proportions of pollutant types other than clothing and detergents are shown in an intuitive graphical manner. They help to understand the proportion of each type in the total amount of pollutants and help to identify the types of pollutants that may need to be focused on during the washing process.

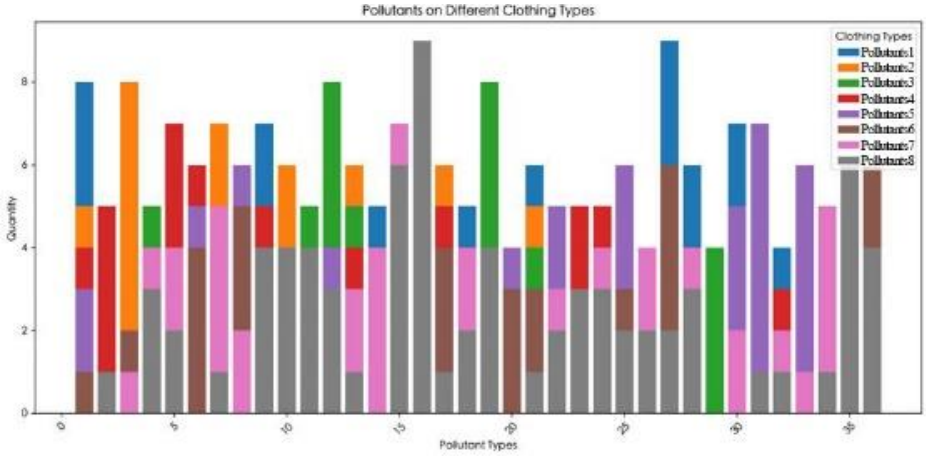



**Fig. 6** Data visualizations

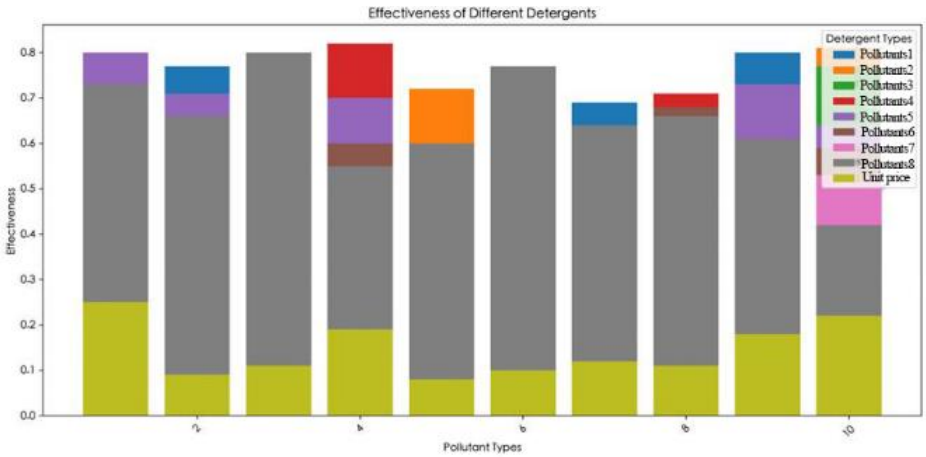



**Fig. 7** Data visualizations

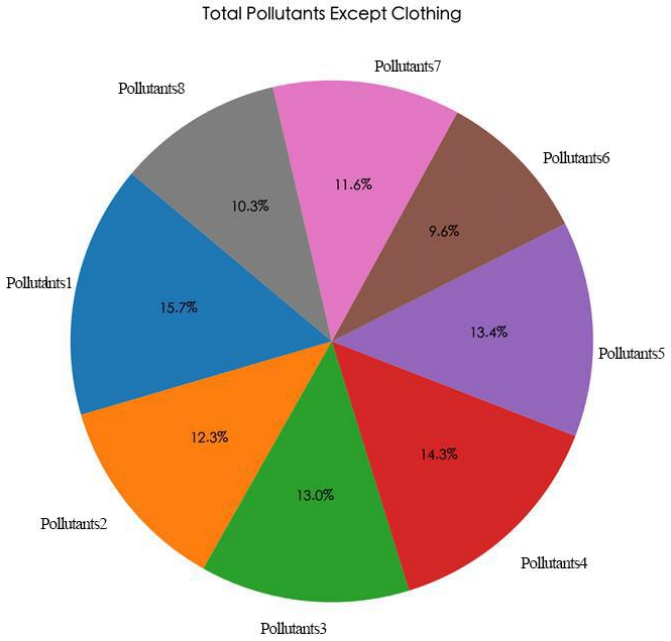



**Fig. 8** Total Pollutants Except Detergent

## 5. Conclusions

The washing model developed in this study brings significant advantages in practical applications, integrating numerous factors within specific constraints for a wide application range. Its comprehensive parameter settings effectively transform problem conditions into mathematical terms, enabling the provision of near-optimal solutions efficiently. However, the model has limitations, including the omission of key factors like temperature and time, which

influence washing frequency, and the extensive data requirements that may cause inconvenience and instability for large datasets. Additionally, it does not account for the interaction between various influencing factors. Despite these limitations, promoting this model could revolutionize laundry processes. Leveraging advancements in artificial intelligence and Internet of Things technology, the model could enable intelligent washing machines to automatically select the most appropriate washing methods and detergents and facilitate a laundry app providing personalized washing advice. This would not only make washing more efficient and tailored to individual needs but also contribute to environmental protection by optimizing resource use and reducing pollution [6].

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