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Design of Damascus Rose Essential Oil Extraction and Comprehensive Utilization Based on TRIZ Theory

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Abstract: With the increasing level of China's national consumption, the people's demand for high-end consumer products such as rose essential oil is growing rapidly. However, rose essential oil is characterized by low oil yield, a complex purification process, and waste material after extraction that is difficult to handle, thus resulting in high production costs. To address the above problems, this study applies TRIZ theory for problem-solving, establishes the root causes in the system by using causal analysis, ideal solution analysis, and functional analysis, and analyzes and solves them by using TRIZ tools such as contradiction matrix, physical contradiction, object-field model, and effect knowledge base, and ultimately arrives at 16 solutions. The above solutions were evaluated for cost and feasibility, and finally, 10 feasible solutions were identified, and a new process route for the extraction of essential oil from Damascus rose with low cost and high waste utilization was further developed and implemented in the project. In the improved new extraction process, the oil-water secondary separation system is designed, the reverse osmosis concentration of pure dew + concentrated pure dew re-evaporation process is introduced, the oil-water separation technology is improved, the essential oils in the pure dew are further extracted, and the post-extraction wastes are made into organic fertilizer, rose soap, and so on, thus improving the yield of the rose essential oils and the comprehensive utilization rate of the products. According to the statistics of the commissioned project, the new Damascus rose essential oil extraction process designed by applying TRIZ theory makes the extraction rate of rose essential oil increase by more than 100%, and the utilization rate of the waste material reaches more than 95%, which creates high economic benefits and further reduces the harm of the production to the environment, and this study provides technical references for the research on the extraction process of essential oils of plants and comprehensive utilization of the waste material.

Keywords: TRIZ theory; Rose essential oil extraction; Comprehensive utilization; Functional analysis

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1. Introductory

As shown in **Figure 1**, Damascus rose essential oil is known as "liquid gold" because of its low yield (4,000–6,000 kg of roses produce 1 kg of essential oil), high efficiency, and high technical difficulties in extraction, resulting in a high price of up to 6,000 U.S. dollars/kg [1]. It contains a variety of amino acids and nutrients, which have the effect of improving skin elasticity and slowing down the aging process, and is a natural and non-irritating high-end skin nourishment [1].

Figure 1. Damask rose and essential oil products [1]

However, the current world production of rose essential oil is about 4 tons, of which the main producing countries Bulgaria and Turkey occupy more than 80% of the international market share, while China's production of essential oil is only about 200 kilograms, which is far below the market share [2–3]. Foreign countries have a complete set of Damascus rose essential oil extraction technology, and the relevant field has realized the technology monopoly, its extraction technology is mainly water vapor extraction, with ultrasonic extraction, supercritical carbon dioxide extraction, and other technologies [4]. China released the domestic standard of Damascus rose essential oil in 2022, and is developing and exploring the high-end cosmetic market [5].

In recent years, major companies in China have been expanding their essential oil production by designing new oil-water separators to increase the separation rate of rose oil [6–7]. Huang and others designed an integrated lavender essential oil extraction device, which receives the condensate in the condenser through a condensate circulation control device to circulate the condensate through a water chiller to cool the condensate and places a circulating switching valve at the lower end of the oil-water separator to realize the secondary separation and extraction of the essential oil of roses [8].

Gan designed an oil-water separator for rose essential oil extraction, which is provided with an oil-water lifting mechanism [9]. Through the coordinated design of the body of the oil-water separator device, the lifting and sprinkling mechanism, the lifting and sprinkling plate, the telescopic rod, the spray nozzle, the sweeping brush, the oil discharge valve, and the oil-water lifting mechanism, it is possible to regulate the height of the oil-water dividing line, which in turn facilitates the separation of the oil and water, and it is possible to achieve a good oil-water separation effect.

However, there is a large amount of rose essential oil dissolved in the pure dew in the above scheme, and there is still room for further extraction. In addition, there are problems in the system such as difficulty in utilizing the waste residue after extraction. Therefore, this project is aimed at solving the common problems of low yield of Damascus rose essential oil, product waste that is difficult to utilize, low degree of automation, and so on. The project research is carried out to develop a comprehensive utilization scheme for the extraction of Damascus rose essential oil products that achieves high yield and high utilization, to reduce the cost of production of Damascus rose essential oil, to satisfy the consumption demand of the people and to strengthen the country's industry competitiveness in the high-end consumer products, such as natural essential oils [10–11].

2. Problem description and analysis

2.1. TRIZ theory

The Theory of Inventive Problem Solving (TRIZ Theory) is a systematic approach to innovation that was developed in the 1940s by a team of researchers led by the Soviet scientist Altshuller through the analysis and study of 2.5 million patents, to help solve complex problems and promote innovation [12]. Innovation using TRIZ theory usually begins with defining the problem, clarifying the nature of the problem and the goal of its solution, and identifying the contradictions, such as the mutual constraints that exist in the system, using methods such as constructing a functional model.

This is followed by invention problem solving, where contradictions are resolved by utilizing the tools and methods provided by the TRIZ theory, including contradiction matrices, effect knowledge bases, and material field analyses [13]. In addition, potential solutions can be generated based on TRIZ principles and models, including reverse thinking, maximizing the use of resources, changing the state of an object, and so on. Afterward, the generated solutions are evaluated, considering their feasibility, benefits, and viability, and the most promising and feasible solutions are selected. Finally, the selected solutions are put into practice and optimized and improved based on feedback [14].

2.2. Description of the problem

Traditional Damascus rose essential oil extraction process uses steam distillation extraction, through the heating device to heat the water to produce water vapor, so that the rose essential oil achieves vapor volatilization. The condensing device will produce essential oil vapor as a water vapor mixture after condensation. The density of essential oils and water are different, so the use of separation devices produces the rose essential oil phase and the purified dew (aqueous phase) in both static separations for the production of Damascus rose oil products. The process is shown in **Figure 2**.

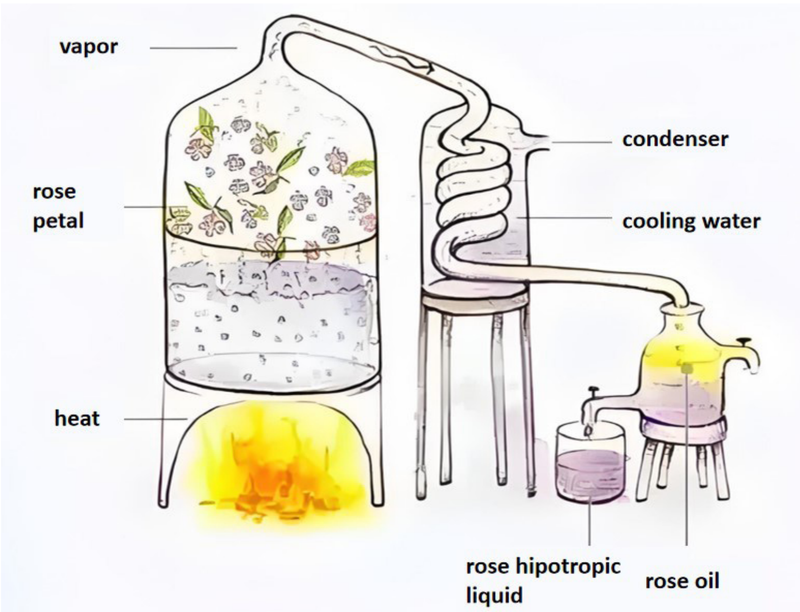

Figure 2. Traditional rose essential oil distillation and extraction process

The traditional rose essential oil extraction process is relatively simple, but the oil-water separation is poor, slow, and incomplete. Therefore, the yield of rose essential oil prepared by this process method is low and faces the following problems.

It is difficult to accurately separate the rose essential oil from the pure dew, which easily causes a small part of the essential oil to overflow into the pure dew, causing the impurity content in the essential oil to become too high, hence the efficiency of the static separation method is low.

Dissolving part of the essential oil in the pure dew will cause waste of essential oil.

A low utilization rate of post-extraction waste, resulting in rose solid residue, distilled flower pulp, and excessive pure dew and other waste, waste is difficult to deal with, and direct discharge is prone to cause environmental problems.

Rose essential oil extraction equipment with a low degree of automation, to a certain extent, the distillation temperature can make the essential oil evaporation faster, and improve the preparation efficiency. However, the distillation temperature being too high will make the essential oil amino acids and other substances decompose, triggering a decline in the quality of essential oil and other issues. How to accurately determine the distillation temperature and time is a challenge in actual production.

2.3. Problem analysis

The goal of TRIZ theory is to solve the contradictions existing in the system through innovative methods and move toward the ideal solution. The innovative solution process mainly consists of the following two stages. The first stage is to analyze the problems in the system, including the establishment of a functional model, ideal solution analysis, and the construction of a causal chain model to determine the minimization problems existing in the system, which is the way forward for the improvement of the system. The second stage is to solve the minimization problems by using innovative methods of the TRIZ theory, such as the theory of conflict resolution, the matter-field model, and the theory of functional effects, to optimize the system toward the ideal state. The second stage is to use the innovative methods in TRIZ theory, such as the conflict resolution theory and the functional effect theory, to solve the minimization problem derived from the analysis in the first stage, so that the system can be optimized to the idealized state. The analytical solution process is as follows (**Figure 3**).

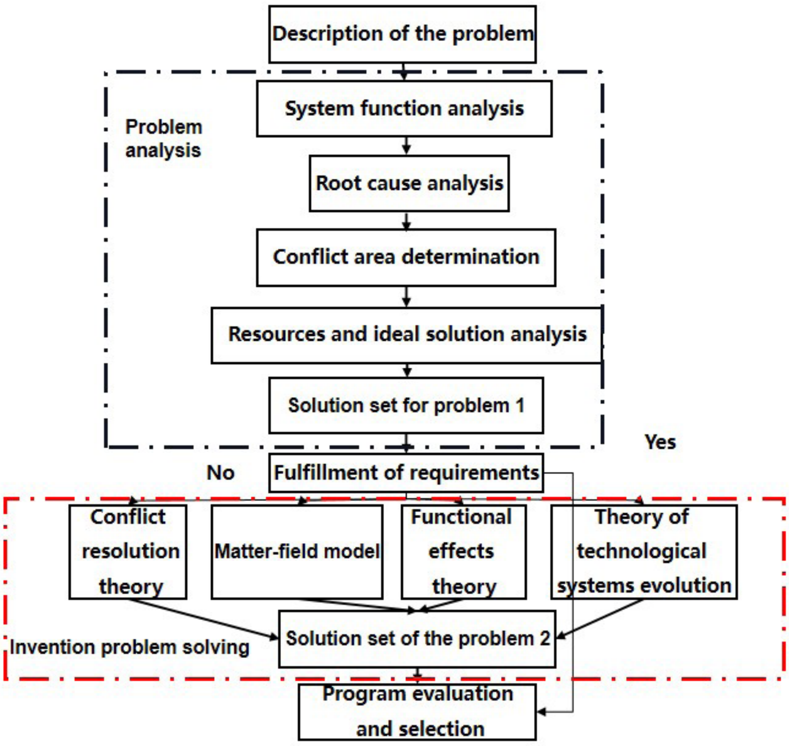

Figure 3. Problem-solving process of TRIZ theory

2.3.1. System functional analysis

Functional analysis is to analyze the role of each component in the system from a functional point of view and to decompose the function of the research object. Functional analysis includes the decomposition of functions, the establishment of the interaction matrix and functional model diagrams, tailoring, and so on. The purpose is to improve the function of the components in the system, to eliminate the harmful effects, to simplify the components in the model of the system, and to remove unnecessary design aspects [15].

In the system functional analysis, firstly, the component analysis of each component is carried out, and the function and performance level of the components in the system are described by establishing the system functional model. As shown in the functional model diagram, the technical system is a distillation and extraction system for Damascus rose essential oil, in which rose essential oil and rose puree are the products, the heating device, reaction tank, condensation device, and separation device are the system components, and the stand and external environment are the supersystem components (**Figure 4**).

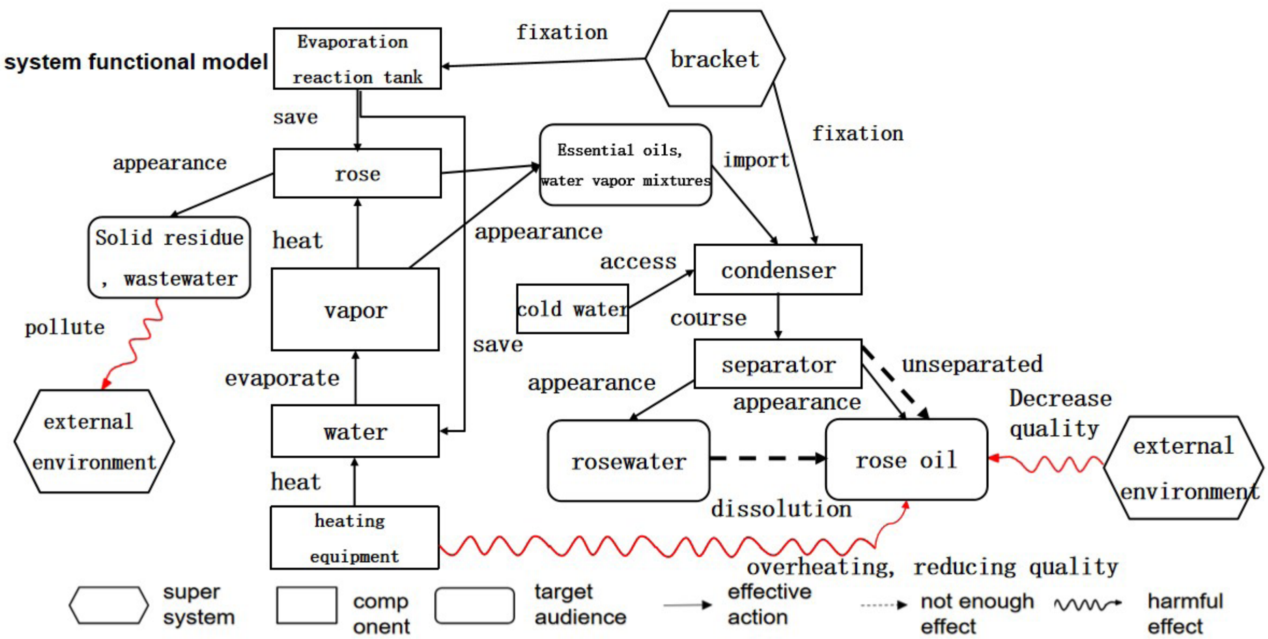

Figure 4. Extract system function model

In the functional model of the rose essential oil extraction system, it can be seen that the deficiencies in the system are the insufficient separation of essential oils, and the harmful effects are the environmental hazards of solid residue and wastewater discharges after extraction, as well as the high distillation temperature affecting the quality of essential oils. For this reason, the above problems need to be further analyzed to eliminate the deficiencies and harmful effects in the system.

2.3.2. Causal chain analysis

Causal chain analysis is a method of analysis that analyzes the relationship between the results produced by a series of events and the causes of those events through causal logic, to identify the most basic causes of problems in a system, also known as root causes [16].

According to the functional analysis of the system, it was found that the main problems in the current rose essential oil extraction system are the low yield and quality of rose essential oil and the low utilization of post-extraction waste, so the causal chain of the system was analyzed as follows (**Figure 5**).

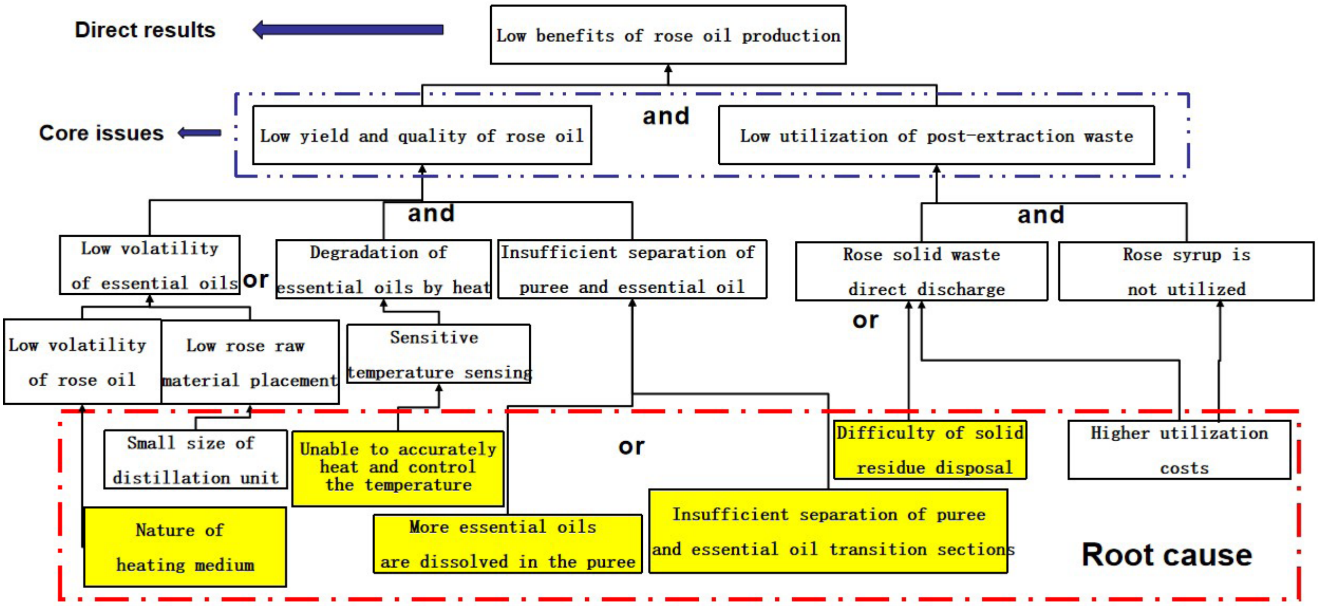

Figure 5. A systematic process of causal chain analysis

Through the causal chain analysis of the rose essential oil extraction system, it is found that the root causes of the low production efficiency of Damascus rose essential oil are the failure to separate the pure dew from the essential oil, the complexity of the solid residue treatment technology and the difficulty of precise temperature control in the extraction process, so it is necessary to solve the above root causes to optimize them. This program focuses on the in-depth study of the root causes such as the difficulty of separating the essential oil and pure dew, and the difficulty of treating the waste residue after extraction.

2.3.3. Ideal solution analysis

The ideal final result (IFR) is the ideal state of the system after evolution, such as cost reduction, increased functionality, and so on. Ideal solution analysis is an idealization process in which the system is improved from the starting point to the ideal solution, during which the deficiencies of the original system are eliminated and no new defects are introduced.

The final ideal solution is the maximum idealized state of the solution system, where there are no defects or deficiencies in the system, which is often difficult to achieve in real production. Usually, some level below the final ideal solution is often adopted as the goal of system solution improvement. In this study, the ideal solution analysis process is as follows in **Table 1** to increase the yield of rose essential oil and reduce waste pollution as the improvement direction of the system.

According to the ideal solution analysis, increasing the volume of the evaporation device increases the amount of rose essential oil vapor evaporated, thereby making the rose essential oil preparation more efficient. A catalyst that can easily volatilize the rose essential oil can be added to the extraction water or configured as a solution to reduce the solubility of the essential oil vapors in the water to accelerate their separation.

To address the issue of ensuring the quality of essential oil, the space resources around the system can be fully utilized to establish a rose plantation industrial park around the extraction line to reduce transportation costs and ensure the quality and freshness of the roses. In addition, the precise automatic temperature control of the extraction process can be realized by installing precision sensors and other measures, and the heat energy generated during the distillation can be used to dry the rose residue to make by-products and so on.

Table 1. Ideal solution analysis process

Question	Analysis of the results
Design end goal	Realization of high efficiency and comprehensive utilization of rose essential oil products
What is the ideal solution	Precise control of temperature to ensure the quality of essential oils; precise separation to improve the yield and purity of essential oils; no pollution of waste materials.
What are the obstacles to reaching the ideal solution	Some of the essential oils are dissolved in the puree, and the cost of waste disposal is high.
What are the causes of this disorder	No low-cost waste treatment technology, no precise heating and temperature control equipment, no large-capacity essential oil evaporation system, no precise separation technology
What are the conditions for not having this disorder	Equipped with a large space for distillation, sufficiently high precision temperature control, low-cost waste treatment technology, more accurate separation of pure dew and essential oils, and a heating medium conducive to the volatilization of essential oils.
What are the available resources	Catalysts, heat, people, sites

3. Analyze the solution using TRIZ theory

3.1. Structural design and optimization of new oil-water separation system

For rose oil and pure dew that need to use a separation device to make the two separations, the traditional separation method uses static separation, which is simple but the preparation efficiency is low. This is because the rose oil and pure dew are difficult to be accurately separated, so the two have a considerable degree of non-separation phenomenon.

This study draws on Bernoulli's principle from the TRIZ theory effect knowledge base to design a novel oil-water separation system structure as shown in **Figure 6** to achieve a secondary separation between essential oil and pure dew. According to Bernoulli's law and the continuity equation, the fluid in the U-shaped pipe flows through the bend to generate centrifugal force, which counteracts the friction resistance and thus reduces the pressure loss in the pipe. In addition, the fluid enters into the pipe that will be bent to form two fluid movement paths, which realizes the precise separation between the rose oil and the pure dew, which is conducive to the separation of more essential oils and the efficient enhancement of the yield of rose essential oil. According to the statistics of the commissioned projects, this secondary oil-water separation device can increase the extraction rate of Damascus rose essential oil by more than 30%.

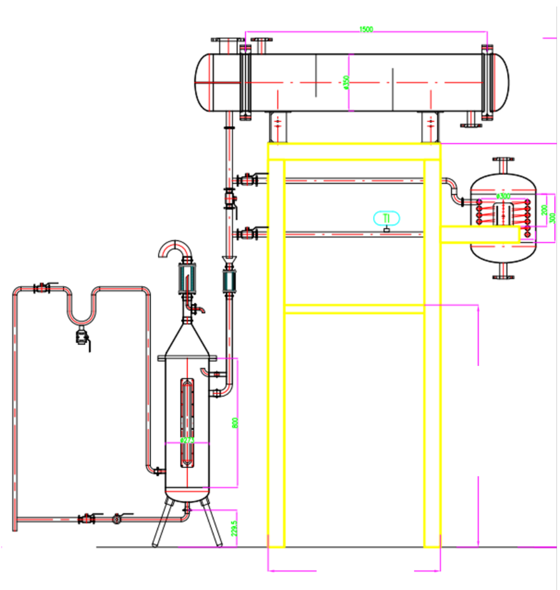

Figure 6. Structure of the new oil-water separation system

3.2. Rose pure dew reverse osmosis concentration device and concentration and re-evaporation process design

Generally speaking, rose essential oil is not soluble in water, however, in large-scale industrialized production of Damascus rose essential oil products, there will be a higher content of rose essential oil dissolved in the pure dew, and one of the root causes of the problem of essential oil waste.

As shown in **Figure 7**, to address the problem of excessive dissolution of essential oils in the puree, the design of a device for further extraction would increase the yield of essential oils, but at the same time increase the complexity of the system, corresponding to the parameters 26 (amount of substance) and 36 (complexity of the system). Therefore, by consulting the matrix of contradictions, it can be seen that it corresponds to the inventive principle 3 (localized mass), principle 13 (reverse action), principle 27 (mechanical system substitution), and principle 10 (pre-action).

	Specific parameters	Common parameter
Improvement parameters	Yield of rose essential oil	No.26 Quantity of Matter
Deterioration parameters	Complexity of essential oil extraction equipment	No.36 Complexity of Systems

Improvement parameters / Deterioration parameters	Complexity of the system
Quantity of matter	3，13，27，10

Figure 7. Schematic of the contradiction matrix

In this regard, this program is analogous to the desalination process and draws on the principle of reverse action, mechanical system substitution, the principle of reaction, the design and establishment of the rose oil reverse osmosis concentration device, and the establishment of concentrated pure dew re-steaming system.

This project introduces the reverse osmosis concentration device and concentration and re-evaporation process of rose pure dew, as shown in **Figure 8**. The system includes ceramic membrane equipment, reverse osmosis membrane equipment, a double-effect concentrator, and so on. For the rose pure dew after separation, it can be introduced into the reverse osmosis concentration device for reverse osmosis concentration of the essential oil in the rose pure dew, and after filtration and re-evaporation process, it can realize the secondary extraction of the essential oil of Damascus rose, and further improve the yield of essential oil of Damascus rose. According to the statistics of the commissioned projects, the extraction device can increase the extraction rate of Damascus rose essential oil by more than 70%.

Figure 8. Reverse osmosis concentration equipment

3.3. Aerobic fermentation solid residue treatment and flower pulp pigment extraction process design

When the rose essential oil is extracted, the equipment will produce moist rose solid residue as flower pulp in the evaporation tube. The rose pure dew contains very little essential oil, while the waste residue and flower pulp are difficult to deal with, because of the high cost of recycling, so the factory usually directly discharges the waste, which will lead to environmental pollution and other problems, as well as the waste of resources.

As shown in **Figure 9**, for the root cause of the difficulty in utilizing the waste material after extraction, this scheme uses the substance-field model in TRIZ theory to solve the problem and adopts 1.1.3 (external addition), 1.2.1 (introduction of new substances), 1.2.4 (elimination of harmful effects), and 17 (change of the macro into the microscopic) of the 76 standard solutions, and arrives at the scheme to introduce the bio-fermentation device, and mechanically mix and pulverize the flower residue to make organic fertilizers to make bio-health products, and so on.

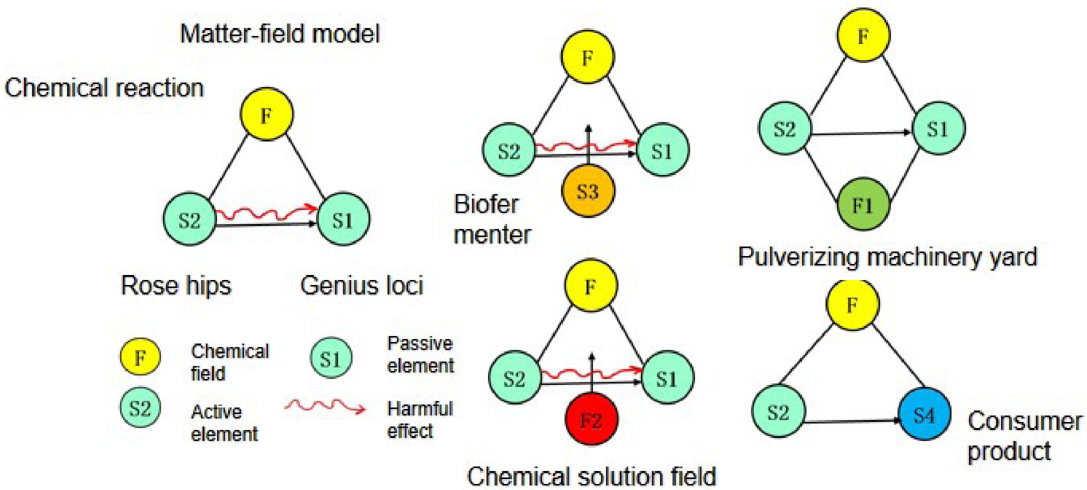

Figure 9. Matter-field modeling

The solution introduces an aerobic fermentation solid residue treatment process, as shown in **Figure 10**, which includes a material crushing device, an oxygen circulation device, a biological deodorization device, and so on, which can ferment the rose solid residue and ultimately produce pure natural organic fertilizers, which can enable the production line to create additional benefits, and can help to further reduce the manufacturing cost of the Damascus rose essential oil products. In addition, the solution introduces a rose pulp pigment extraction process, which includes a ceramic filtration device, a double-effect concentration and extraction device, and so on, which can concentrate and enrich the flower pulp remaining after extraction to produce high-value rose pigments and other products.

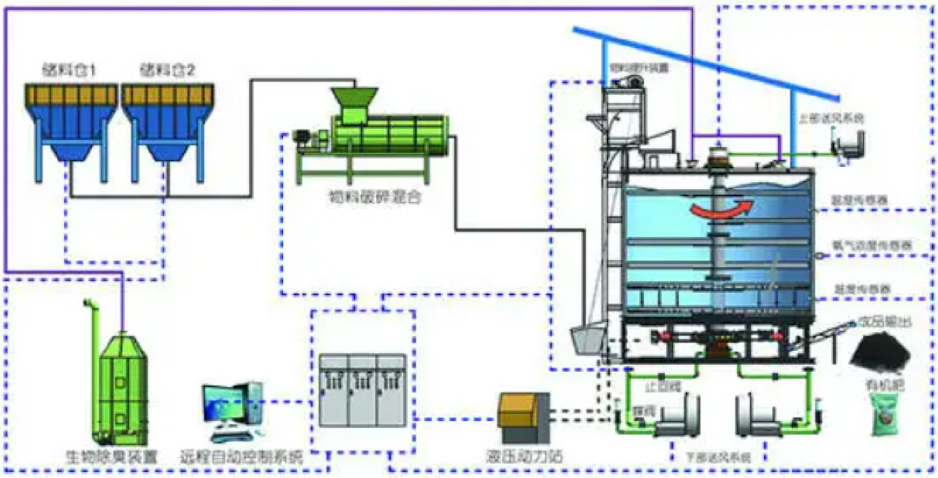

Figure 10. Aerobic fermentation solid residue treatment process

4. Innovative program evaluation and project validation

4.1. Evaluation of innovative programs

The programs were summarized and then evaluated on the parameters of feasibility, cost and effectiveness evaluation, and so on, resulting in the following program evaluation table (**Table 2**).

Table 2. Program evaluation form

Prescription	Principle used	Costs	Enforceability	Effectiveness evaluation
Increase the volume of the rose oil evaporator	Ideal solution analysis	low	Highly	Executed
Improving the accuracy of temperature sensors in control systems	Ideal solution analysis	costly	Weak	Not considered at this stage
Add a catalyst that volatilizes the rose essential oil	Analysis of resources	middle	middle	Under implementation
Change of heating medium to carbon dioxide extraction	Analysis of resources	costly	Weak	Not considered at this stage
Establishing a rose industrial park around the area to reduce transportation costs	Analysis of resources	middle	middle	Executed
Drying of roses using heat from distillation extraction	Analysis of resources	costly	Highly	Executed
Designed with a separation device that allows for a secondary separation of the transition between the pure dew and the essential oil.	40 Invention Principles	middle	middle	Executed

Table 2 (continued)

Prescription	Principle used	Costs	Enforceability	Effectiveness evaluation
Design of fluid separation units with U-tubes	Effects Knowledge Base	low	Highly	Executed
Utilizing a reverse osmosis unit to concentrate pure dew with a high rose essential oil content	40 Invention Principles	costly	Highly	Executed
Concentrated pure dew is introduced into the evaporation and extraction device, and the pure dew is circulated and re-evaporated.	40 Invention Principles	costly	Highly	Executed
Introducing flower residues into the biofermentation unit and applying them as fertilizer to the farmland	Matter-field model	middle	Highly	Executed
The flower residue is mechanically pulverized and discharged to farmland	Matter-field model	costly	middle	Not considered at this stage
The extracted roses are made into plant fiber products, bioproducts, etc.	Matter-field model	costly	middle	Executed
Extraction of rose pigments using ethanol and other reagents	40 Invention Principles	middle	Highly	Executed
Rose pigment extraction using ultrasonic treatment and other methods	40 Invention Principles	costly	Weak	Not considered at this stage
Extraction of essential oil molecules by vibration using microwave radiation	40 Invention Principles	costly	middle	Executed

By summarizing and then evaluating the innovative solutions such as the above, several feasible solutions have been derived, which provide a reference for the development of a comprehensive utilization process for the low-cost and high-efficiency extraction of rose essential oil.

4.2. Program validation in projects

As shown in **Figure 11**, it is a new type of Damascus rose essential oil extraction and comprehensive utilization device designed according to the innovative scheme of TRIZ theory.

Figure 11. New Damascus rose essential oil extraction and comprehensive utilization device

The process solution derived from TRIZ theory in the project has been verified by the production test, which solves several problems such as high cost and low utilization rate of post-extraction waste caused by low yield of rose essential oil. According to the statistics of the commissioned projects, the extraction device can increase the extraction rate of Damascus rose essential oil by more than 100%, which has reached the leading level in the industry. In addition, this comprehensive utilization program has prepared several products such as high-quality rose essential oil, bio-organic fertilizer, and rose soap, realizing the dual goals of low-cost recycling of rose essential oil extraction and green energy saving.

In addition to the above solutions, this project introduces an ultrafiltration sterilization device for Damascus rose pure dew, which can realize the industrialization of Damascus rose pure dew products, and can further create new benefits for Damascus rose essential oil products. As shown in **Figure 12**, by utilizing several waste processing techniques and realizing the industrial closed loop, except for a small amount of wastewater that is difficult to utilize, some new benefits are created, resulting in a waste reduction rate of more than 95%, thus realizing the comprehensive utilization of Damascus rose essential oil products, and providing a new solution to reduce the cost of Damascus rose essential oil products.

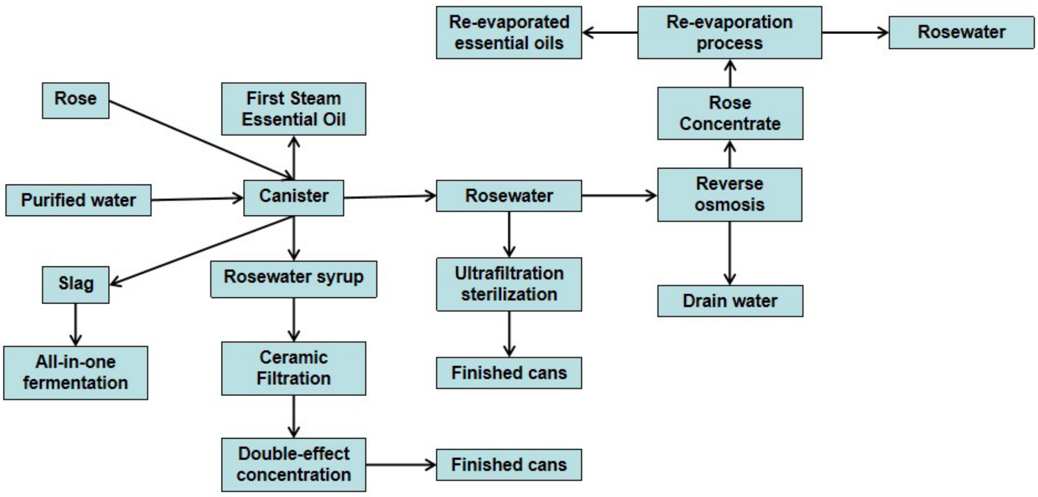

Figure 12. Comprehensive utilization of Damask rose oil products

5. Conclusion

In this study, based on TRIZ theory, process improvement was carried out to address the problems of efficient preparation of essential oil of Damascus rose and improvement of comprehensive utilization. Firstly, the problems in the essential oil extraction system were identified through functional analysis and causal chain analysis, and the technical and physical contradictions in the system were solved through the use of inventive principles, standard solutions, and an effective knowledge base. The program introduces microwave extraction and reverse osmosis extraction means, designs the pure dew reverse osmosis concentration + concentrated pure dew re-evaporation process, improves the oil-water separation technology, and further extracts the essential oils in the pure dews, thus improving the rate of essential oil of Damascus roses and the efficiency of the preparation, and making the post-extraction wastes be comprehensively utilized, and further improving the environment and expanding the production value. According to the statistics of the commissioned projects, the extraction process can increase the extraction rate of Damascus rose essential oil by more than 100%, and the waste reduction rate is more than 95%. The process solution improved according to the TRIZ theory of this project can provide technical reference for the future efficient preparation of essential oil of Damascus rose, improve the efficiency of resource utilization, and reduce the energy consumption of products.

Disclosure statement

The authors declare no conflict of interest.

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