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Techno-economic evaluation of solar distillation system for essential oil extraction from medicinal plants

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Abstract
Energy is an inevitable option for sustainable development and energy saving has become more significant nowadays. The environmental problems such as climate change caused by the overuse of fossil fuels has emerged as one of the biggest challenges for the world. In this regard, renewable energy sources such as solar energy, tidal energy, wind energy, biomass energy, etc. could be used to meet the demand of developing countries over the world. Among these sources, solar energy is the most abundant source and solar energy technologies have become a viable option for so many applications in the field of agriculture. This study evaluated the application of solar energy for essential oil extraction and its economic feasibility. It was found that benefit-cost ratio is 1.80 and payback period is 21 months. The study concluded that solar distillation system is an economically feasible method for essential oil extraction.

Keywords: Solar, economic analysis, essential oil, distillation

1. Introduction

Renewable energy, particularly solar power, stands as a beacon of hope in the global pursuit of sustainable energy sources (Cuce and Cuce, 2013) [1]. Harnessing the virtually limitless energy emitted by the sun, solar power has emerged as a leading contender in the fight against climate change and the quest for energy independence. Solar panels, comprised of photovoltaic cells, convert sunlight into electricity with remarkable efficiency. Moreover, advancements in solar technology have made it increasingly affordable and accessible, democratizing energy production and empowering communities worldwide. From sprawling solar farms dotting deserts to rooftop installations on homes and businesses, solar energy is revolutionizing the way we power our world, offering a clean, abundant, and renewable alternative to fossil fuels.

Beyond its environmental benefits, solar energy also promises economic prosperity and social equity (Buratti and Muretti, 2012) [2]. By tapping into the sun's energy, nations can reduce their dependence on costly and volatile fossil fuels, mitigating the economic risks associated with fluctuating oil prices and geopolitical tensions. Furthermore, the decentralized nature of solar power allows individuals and communities to take control of their energy production, fostering local resilience and reducing disparities in energy access. As governments, businesses, and individuals increasingly recognize the potential of solar energy to drive sustainable development, investments in solar infrastructure continue to soar, paving the way for a brighter, cleaner, and more equitable energy future.

Solar energy holds tremendous promise in revolutionizing post-harvest operations across various agricultural sectors, offering sustainable solutions to preserve and process crops efficiently. In regions where access to electricity is limited or unreliable, solar-powered technologies present an invaluable opportunity to extend the shelf life of harvested produce and reduce post-harvest losses. Solar dryers, for instance, provide an eco-friendly alternative to traditional drying methods, allowing farmers to efficiently dehydrate fruits, vegetables, grains, and herbs using solar heat. By harnessing the power of the sun, these dryers not only accelerate the drying process but also maintain the nutritional integrity and quality of the harvested crops, ensuring higher market value and reducing food waste (Belessiotis and Delyannis, 2011) [4].

Moreover, solar energy finds innovative applications in essential oil extraction, offering a sustainable and environmentally friendly approach to producing high-quality botanical extracts. Solar distillation systems utilize solar heat to vaporize aromatic compounds from plant materials, such as flowers, leaves, and seeds, and then condense them into essential oils (Munir and Hensel, 2010) [3]. This solar-powered extraction method not only eliminates the need for fossil fuels but also minimizes greenhouse gas emissions and chemical residues, resulting in purer and more natural essential oils (Hilali *et al*., 2019) [7]. From lavender and rosemary to citrus fruits and eucalyptus, solar-powered essential oil extraction holds immense potential for small-scale farmers, cooperatives, and artisanal producers seeking to harness the healing and aromatic properties of plants while promoting sustainable agricultural practices. By integrating solar energy into post-harvest operations and essential oil extraction processes, communities can enhance food security, promote rural livelihoods, and contribute to a more sustainable and resilient agricultural sector. This study was conducted to analyse the economic feasibility of solar distillation system.

2. Materials and Methods

2.1 Solar Based Distillation System (SBDS)

SBDS was developed to extract essential oil from medicinal and aromatic plants. The major components of the system were solar concentrator, secondary reflector, distillation still and condenser. The Scheffler concentrator acted as a pivotal apparatus for providing energy. Within the distillation still, botanical material placed above water underwent thermal exposure induced by the concentrated solar energy. This thermal elevation initiated the vaporization of water, concurrently entraining the essential oils present within the botanical matrix. Transitioning from vapor phase to liquid, the laden vapor traversed to the condenser, where it encountered conditions conducive to condensation. The condensed mixture was collected and separated (Munir *et al*., 2014) [6]. The lemongrass leaves were dried and extracted oil from it using the developed system.

2.2 Economic analysis

Economic analysis of systems is highly relevant across various domains due to its ability to provide insights into how different components within a system interact and influence each other economically. Economic analysis of the SBDS was carried out by following indicators (Afzal *et al*., 2017) [5].

1. Net Present Worth (NPW)
2. Benefit-Cost Ratio (BCR)
3. Internal Rate of Return (IRR)
4. Payback Period (PP)

2.2.1 Net present worth (NPW)

The net present worth or NPW is a measure of the difference between the current value of all future returns and the initial investment required. It is based on the principle of discounting, where future returns are adjusted to their present value. Discounting involves converting future benefits and costs into their current equivalents using an assumed interest rate as the discount rate. For instance, if a project yields consistent benefits over several years, NPW helps determine how much it's worthwhile to invest today to receive those future returns. Essentially, NPW was calculated by subtracting the total discounted present value of the cost stream from that of the benefit stream, providing a straightforward measure of project worth based on discounted cash flows.

$$NPW = \sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t} \qquad (1)$$

Where,
C_t= Cost in each year
B_t= Benefit in each year
t = 1, 2, 3.n (years)
i = Discount rate, %

2.2.2 Benefit cost ratio

The benefit-cost ratio is a financial metric used to assess the economic viability of a project or investment. It involves comparing the present value of benefits to the present value of costs associated with the project. By calculating this ratio, it can be determined whether the benefits of the project outweigh the costs, with a ratio greater than 1 indicating a favourable investment. This analysis helps in evaluating the efficiency and desirability of projects by considering their long-term financial implications. This is the ratio obtained when the present worth of the benefit stream is divided by the present worth of the cost stream. The present value of benefits and costs was calculated by discounting future cash flows back to their present values using the chosen discount rate. Mathematically benefit-cost ratio can be expressed as:

$$\text{Benefit cost ratio} = \frac{\sum_{t=1}^{t=n} B_t}{\sum_{t=1}^{t=n} C_t} \qquad (2)$$

Where,
C_t = Cost in each year
B_t = Benefit in each year
t = 1, 2, 3.n (year)
i = Discount rate

2.2.3 Payback period

The payback period is a financial metric used to evaluate the time it takes for an investment to recover its initial cost. It offers a simple and intuitive way to assess the risk and return of investment projects, particularly for those seeking quick returns or concerned about liquidity. Essentially, the payback period indicates the length of time required for the cumulative cash flows generated by the investment to equal or surpass the initial investment amount. The payback period is then expressed in terms of the number of periods (e.g., months or years) it takes to recover the initial investment.

$$\text{Payback period} = \frac{\text{Total investment}}{\text{Net profit}} \qquad (3)$$

2.2.4 Internal rate of return

An alternative way to assess a project's value is by determining its internal rate of return (IRR), which identifies the discount rate that sets the net present value of incremental cash flows to zero. Essentially, IRR represents the maximum interest rate the project could handle while still covering its costs and breaking even. It reflects the return on invested capital over each period, offering a crucial measure of profitability. The IRR is calculated through a trial-and-error process to find the discount rate that balances the present value of cash inflows and outflows, revealing the project's break-even point and providing valuable insights into its economic viability.

$$\text{IRR}= \sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t} \quad (4)$$

3. Results and Discussion

The economic feasibility of the SBDS for essential oil extraction from medicinal plants was calculated by considering the initial investment, average repair and maintenance costs, and the cost of raw materials and oil obtained. The average parameters are drawn on the basis of experimental results. The different economic parameters for essential oil extraction from using SBDS are summarized in Table 1.

Following points were considered to carry out the economic analysis of the SBDS

1. The capacity of the distillation system was 20 kg.
2. The initial cost of distillation system was Rs. 100000 and the cost of Scheffler solar collector was Rs. 3, 00,000.
3. Two batches were considered per day.
4. The operating days of solar distillation system was considered as 200 days.
5. Labour cost was considered to be 250 Rs/day
6. Repair and maintenance cost of the system was assumed to be 10 percent of total capital cost per year.

3.1 Net present worth (NPW)

The net present worth of the SBDS was calculated based on present investment and the interest rate considered for the system and the profit achieved in each year. The life of the developed system was assumed as 10 years. Thus, the net present worth of the system was Rs. 961144.51/- for lemongrass (Considering 200 days in a year) as shown in Table 1. The net present worth was calculated for next 10 years.

Table 1: Economics of solar biomass hybrid distillation system using citronella

Sr. No.	Parameters	Values	Unit
1.	Capacity of machine	20	kg
2.	Capital cost of machine	4,00,000	Rs.
3.	No of days of operation in a year	200	days
4.	No of batches per day	2	batch/day
5.	Life of system	10	Yr
6.	Repair and maintance cost (10% of capital cost)	40000	Rs.
7.	Total cost of material per year	40000	Rs.
8.	Cost of Electricity unit consumed per year	480	Rs/yr
A)	Cost of Production include repair and maintenance cost	130480	Rs
B)	Market value of the citronella essential oil	352000	Rs
11.	Net Profit per year (B-A)	221520	Rs/yr
12.	Payback Period (Capital cost/Net profit)	1 Year 9 Months	-
13.	Payback Period	21	months

3.2 Benefit-cost ratio (BCR)

The benefit-cost ratio of the developed system was calculated by dividing the present worth of the benefit stream to the present worth of the cost stream. For lemongrass, present worth of the benefit stream was Rs. 342560.33/- whereas the present worth of the cost stream was Rs. 327876.16/-. The benefit-cost ratio of the developed system was found to be 1.80 lemongrass (Considering 200 days in a year).

3.3 Payback period (PP)

The payback period of the developed system was estimated by adding net cash flow in the project until the cumulative net cash flow was equal to the initial investment. It is clear from Table 2 that the developed system has a payback period of 21 months for lemongrass (considering 200 days in a year).

3.4 Internal rate of return (IRR)

The internal rate of return for the solar biomass hybrid distillation system was calculated and found to be 55 percent for lemongrass (10 years). The higher percentage of internal rate of returns indicated the good commercial return of the investment.

Table 2: Economic indicators of SBDS

Sr. No.	Economic indicator	Values
1.	Net present worth (NPW)	Rs. 961144.51
2.	Benefit cost ratio (BCR)	1.80
3.	Payback period (PP)	21 months
4.	Internal rate of return (IRR)	55 percent

4. Conclusion

Essential oils are highly concentrated and aromatic essence of the plants and have various applications in aromatherapy, fragrance, food, and pharmaceuticals. The adoption of renewable energy technology for the essential oil extraction is an innovative and sustainable method. The techno- economic feasibility of SBDS was analyzed. It was found that benefit-cost ratio is 1.80 and payback period is 21 months. Thus, it can be concluded that system is economically feasible.

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