

Research Article

Innovative Formulation and Quality Optimization of Herbal Pain Relief Oil Using Solar Thermal Technology

Sandip Sengar* , Tilak Chavda , Alok Singh , Jay Chaudhari ,
Bhautik Mishra 

Department of Renewable Energy Engineering, College of Agricultural Engineering and Technology, Dediapada, India

Abstract

This study focused on preparing and optimizing herbal pain relief oil using solar thermal technology, specifically a solar box cooker, during winter and summer seasons. The performance of solar device was assessed through stagnation temperature and full-load tests using water and herbal pain relief oil, separately, measuring temperatures inside the cooker and pot, as well as ambient temperature, relative humidity, and solar radiation. Figures of merit (F_1 and F_2) were calculated to evaluate device efficiency. The herbal pain relief oil was formulated with mustard oil and varying proportions of nirgundi leaves (5%, 10%, 15%) and 5% of other raw herbs like ajwain, garlic, fenugreek and turmeric, processed for one or two days. The resulting oil was filtered, stored in sealed glass or plastic bottles, and subjected to laboratory analysis to determine pH, specific gravity, viscosity, acid value, saponification value, and refractive index. Sensory and organoleptic evaluations, including colour, odour, sensitivity, irritation, and overall acceptance, were conducted by 18 panellists, comparing the formulated oil to a commercial product. The optimal formulation, using 15% nirgundi leaves and 5% other herbs heated for two days in the box type cooker, yielded high quality yellowish green oil with a pH of 7.8, specific gravity of 0.92, viscosity of 29.09, acid value of 0.70, saponification value of 29.45, and refractive index of 1.38. This formulation, processed using the box type solar cooker, also demonstrated a profit margin of 50–60 ₹/L, highlighting the economic and environmental benefits of solar thermal technology for herbal oil production.

Keywords

Solar Box Type Cooker, Herbal Pain Relief Oil, Ph, Specific Gravity, Viscosity, Acid Value, Saponification Value, Refractive Index

1. Introduction

Herbal pain relief oils, formulated by blending carrier oils such as mustard oil [5] with essential oils and potent herbs like *Vitex negundo* (nirgundi) [12] and *Curcuma longa* (turmeric) [6], have long been valued for their therapeutic efficacy. These oils provide rapid relief from various types of pain, including muscular aches, joint discomfort, and chronic con-

ditions such as rheumatoid arthritis [6, 22, 26, 32, 35], headaches, and migraines. When applied topically through massage, these formulations alleviate muscle tension, reduce stiffness, and promote relaxation [7]. The growing popularity of essential oil-based therapies reflects a broader trend toward alternative medicine, as evidenced by the expanding market

*Corresponding author: sandipsengar@yahoo.com (Sandip Sengar), shsengar@nau.in (Sandip Sengar)

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for health, aromatherapy, and spa products [25]. Specific herbs incorporated into these oils [3, 17] contribute distinct pharmacological properties. Ajwain (*Trachyspermum ammi*) [1, 33], known for its anaesthetic qualities, mitigates pain and swelling when applied as a crushed seed paste or infused in warm water soaks [4]. Fenugreek (*Trigonella foenum-graecum*) [10], or methi, exhibits anti-inflammatory effects, making it a valuable remedy for joint pain, particularly during colder months [26]. Garlic (*Allium sativum*) [22], when warmed and mixed with a carrier oil, acts as a rejuvenator, enhancing blood circulation, reducing toxins, and relieving joint pain [35]. *Vitex negundo*, [2, 34, 36] referred to in Sanskrit as *nirgundi* meaning "that which protects the body from diseases" is traditionally used to address conditions such as joint pain (*sandhi vata*) [20, 23] and swelling. Similarly, turmeric, often termed "Indian saffron," is renowned for its anti-inflammatory, antioxidant, anticancer, and neuroprotective properties, making it a cornerstone of herbal formulations. The production of herbal pain relief oils has traditionally relied on energy-intensive methods, such as biomass stoves, liquid petroleum gas, or electric heating. However, the abundant availability of solar energy [8, 15] presents an eco-friendly alternative. Solar thermal technologies, particularly box type solar cookers [19, 24, 27, 28, 31, 37, 38], harness solar radiation to heat onto a pot, enabling applications such as cooking, pasteurization, sterilization, and herbal oil preparation [16]. These devices offer significant advantages, including minimal maintenance, low operational costs, long-term durability, and the preservation of bioactive compounds in herbs [29] due to gentle, slow heating. Recognizing these benefits, this study explores the formulation and quality enhancement of herbal pain relief oil using solar thermal technology, aiming to develop a sustainable and effective approach to producing high quality therapeutic oils.

2. Materials and Methods

The performance of the box type solar cooker was assessed through stagnation temperature and full load testing using water and herbal pain relief oil, separately, to evaluate its thermal efficiency.

2.1. Stagnation Temperature Test

Under this test, the solar cooker was positioned in an open, sunlit area without any raw materials or food inside. The air temperature within the cooker and the ambient temperature were recorded hourly from 08:00 to 17:00. Once the cooker reached a steady-state temperature, the maximum internal temperature (T_{max}), the corresponding ambient air temperature (T_a), and the solar radiation intensity (G_s) were documented, following the methodology outlined by [18]. The figure of merit, F_1 , defined as the ratio of optical efficiency to the heat loss coefficient, was subsequently calculated to quantify the cooker's performance.

$$F_1 = \frac{\alpha t}{U_L} = \frac{T_{ps} - T_a}{G_s}$$

Where, F_1 is First figure of merit; T_{ps} is plate temperature of cooker, °C; T_a is ambient temperature, °C and G_s is Solar Radiation, W/m².

2.2. Water Heating Test

An empty pot was precisely weighed prior to being filled with water maintained at an initial temperature of 30 ± 5 °C. The pot was subsequently reweighed to determine the water mass. The pot was positioned within a solar cooker, with its reflective mirror to ensure consistent test conditions. Throughout the experiment, environmental parameters including ambient temperature, solar radiation, wind speed, and relative humidity were continuously monitored. The following procedural steps [18, 19] and measurements were executed:

- 1). The temperature of the water was recorded concurrently with the precise time of each measurement.
- 2). Data acquisition persisted until the water temperature surpassed 95 °C.
- 3). Initial and final temperature time data pairs were selected, with the initial temperature (T_{w1}) ranging between 60 °C and 65 °C and the final temperature (T_{w2}) between 90 °C and 95 °C, corresponding to times t_1 and t_2 , respectively.
- 4). The average ambient air temperature (T_a) was computed over the time interval from t_1 to t_2 .
- 5). The average solar radiation (G_s) was calculated over the same time interval (t_1 to t_2).
- 6). The second figure of merit (F_2) was determined using the formula based on the collected data.

$$F_2 = \frac{F_1(MC)_w}{AT} \left[\ln \left(1 - \frac{(T_{w1} - T_a)}{F_1 G_s} \right) / \left(1 - \frac{(T_{w2} - T_a)}{F_1 G_s} \right) \right]$$

Where, $(MC)_w$ is product of mass of water and specific heat in J/°C; A is aperture area of the cooker of cover plate in m²; T is time taken for heating from T_{w1} and T_{w2} in seconds; G_s is average radiation over time period ($t_2 - t_1$) in W/m².

2.3. Heating Test with Herbal Pain Relief Oil

The composition of the herbal pain relief oil is detailed in Table 1 and Figure 1. The herbs, including ajwain, fenugreek, garlic, and turmeric, were procured and precisely weighed at 25 g each (5% of the total formulation). These were ground and blended with nirgundi leaves at varying proportions of 25 g (5%), 50 g (10%), and 75 g (15%). The herbal mixture was combined with 500 ml of mustard oil and placed in a pot within a box type solar cooker. The mixture was subjected to solar heating for durations of one and two days, as depicted in Figure 2. For comparative analysis, the same formulation was processed using traditional methods on a Chulha for 15 to 20

minutes or until a noticeable color change occurred. Subsequently, the oil was filtered through filter paper or cotton cloth and stored in glass bottles for further organoleptic evaluation, as shown in Figure 2.

Table 1. Composition of herbal pain relief oil.

Ingredients	Quantity (500 ml Base)		
	5% Nirgundi	10% Nirgundi	15% Nirgundi
Mustard oil	500 ml	500 ml	500 ml
Nirgundi Leaves	25 g (5%)	50 g (10%)	75 g (15%)
Ajwain	25 g (5%)	25 g (5%)	25 g (5%)
Fenugreek	25 g (5%)	25 g (5%)	25 g (5%)
Garlic	25 g (5%)	25 g (5%)	25 g (5%)
Turmeric	25 g (5%)	25 g (5%)	25 g (5%)

2.4. Physicochemical Characterization

The formulated herbal pain relief oil was subjected to a detailed physicochemical analysis to determine its pH, specific gravity, viscosity, acid value, saponification value and refractive index, as illustrated in Figure 2.

2.5. Organoleptic Assessment

Organoleptic evaluations were conducted to assess attributes such as sensitivity, irritation, color, and odor. These tests were performed by applying and observing the responses to the herbal oil formulations containing 5%, 10%, and 15% nirgundi, combined with 5% of other herbs (ajwain, fenugreek, garlic, and turmeric). The oils were prepared using a box type solar cooker for one and two days, as well as via traditional methods, to compare their organoleptic profiles.

2.6. Sensory Evaluation

Sensory analysis was conducted at the Department of REE, CAET, Dediapada. Various samples of the herbal oil were presented to a panel of ten trained panelists, selected for their ability to discern and rate a wide range of sensory attributes. The panelists evaluated the oil for sensitivity, irritation, color, and odor using a 9-point hedonic scale (1 = Dislike extremely, 9 = Like extremely). Additionally, a semi-trained panel comprising 18 students and faculty members from CAET, Dediapada, assessed the oils for appearance, color, and overall acceptability on the same 9-point hedonic scale. Panelists, unaware of the project objectives, were provided with samples coded with two-digit random numbers, presented in a counterbalanced order. They were instructed to rinse and swallow water between samples and to evaluate the products based on written guidelines focusing on sensitivity, irritation, color, and odor.

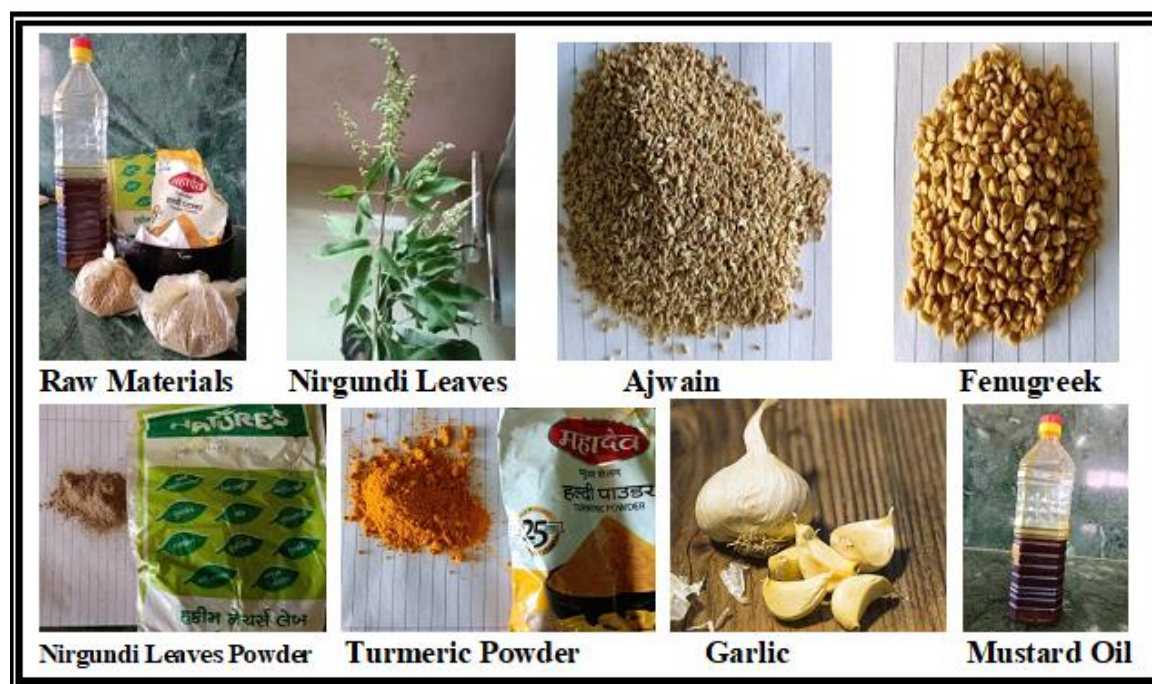


Figure 1. Composition of raw materials for the formulation of herbal pain relief oil.

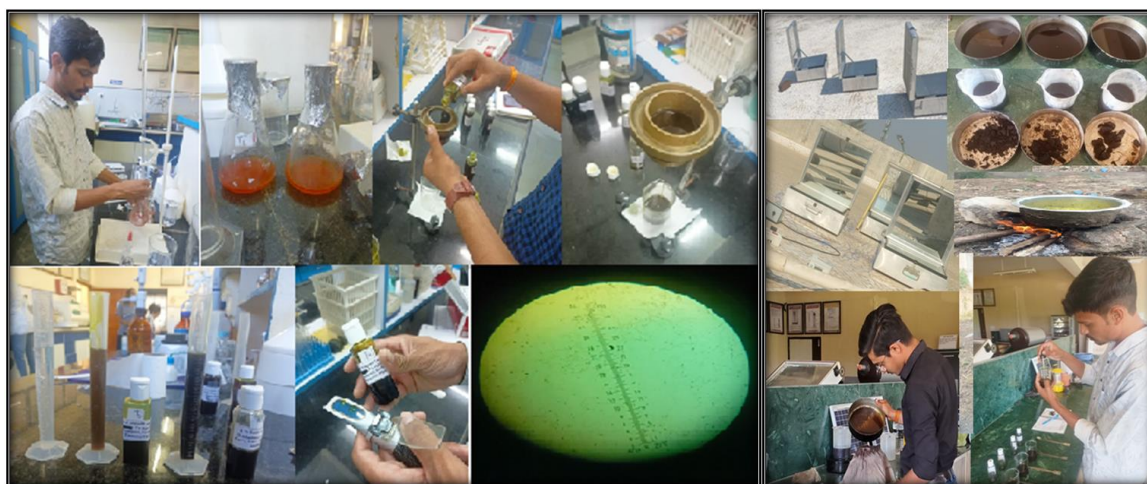


Figure 2. Experimental configuration for the production and filtration of herbal pain relief oil.

2.7. Statistical Analysis

Statistical analysis of the herbal pain relief oil was performed to evaluate significant differences in parameters such

as pH, specific gravity, acid value, saponification value, refractive index, viscosity, color, odor, sensitivity, irritation, and overall acceptability. The data were analyzed for CD values and CV% and were uploaded to the official ICAR website [9] for statistical analysis.

3. Results and Discussion

3.1. Stagnation Temperature Test

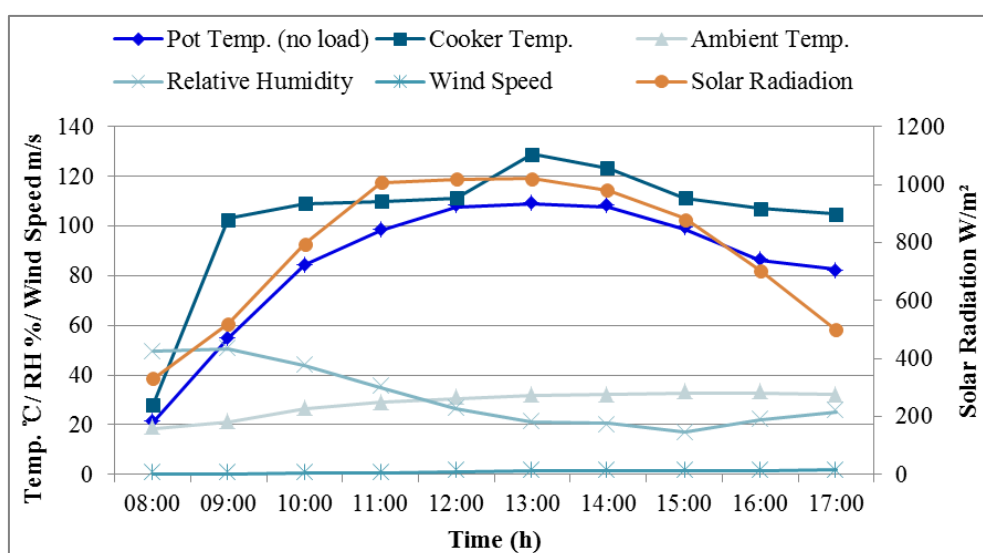


Figure 3. Thermal performance test during stagnation temperature test.

The performance evaluation of solar cooker was carried out in terms of no-load testing and full load testing. The figure of merits F_1 and F_2 was calculated whose values should be greater than 0.11 and 0.38 respectively. The data on no load testing the cooker without containers, with reflector for winter are present in Figure 3. It was observed that the temperature

inside the pot was found more than temperature observed in chamber inside of solar cooker which was 20 °C more. The maximum temperature achieved by cooker was 129 °C in winter at 13:00 hrs meanwhile the ambient temperature was 31.9 °C, humidity was 21%, wind speed 1.2 m/s and solar radiation was observed 1020 W/m².

3.2. Water Heating Test

The performance of box type solar cooker was evaluated with load test as filling water in container with reflector for winter and the variation in solar intensity and ambient air temperature is presented in Figure 4. It was observed that the

average temperature inside the pot was found more than temperature observed in chamber inside of solar cooker which was 6 °C less. The maximum temperature achieved by cooker was 93.85 °C in winter at 15:00 h meanwhile the ambient temperature was 29.05 °C, humidity was 11%, 0.4 m/s wind speed and 749 W/m² solar radiations was observed.

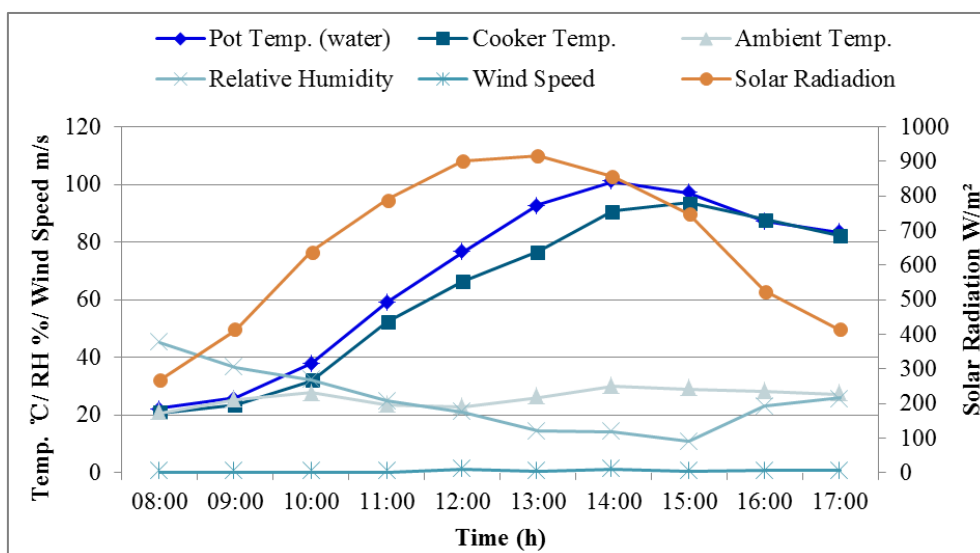


Figure 4. Thermal performance test under water heating test.

3.3. Heating Test with Mustard Oil

The performance of box type solar cooker was evaluated with heating test as filling mustard oil in container with reflector for winter are present in Figure 5. It was observed that the temperature inside the pot was found more than temperature observed in chamber inside of solar cooker which was

less. The maximum temperature achieved by cooker was 131.1 °C in winter at 13:00 h meanwhile the ambient temperature was 33.9 °C, humidity was 14.5%, 1.5 m/s wind speed and 1069 W/m² solar radiation was observed. During the evaluation of box type solar cooker for heating of 500 ml oil testing, no loss was found during the test. It was also observed that oil obtain more temperature than water in box type solar cooker which is around 37 °C more.

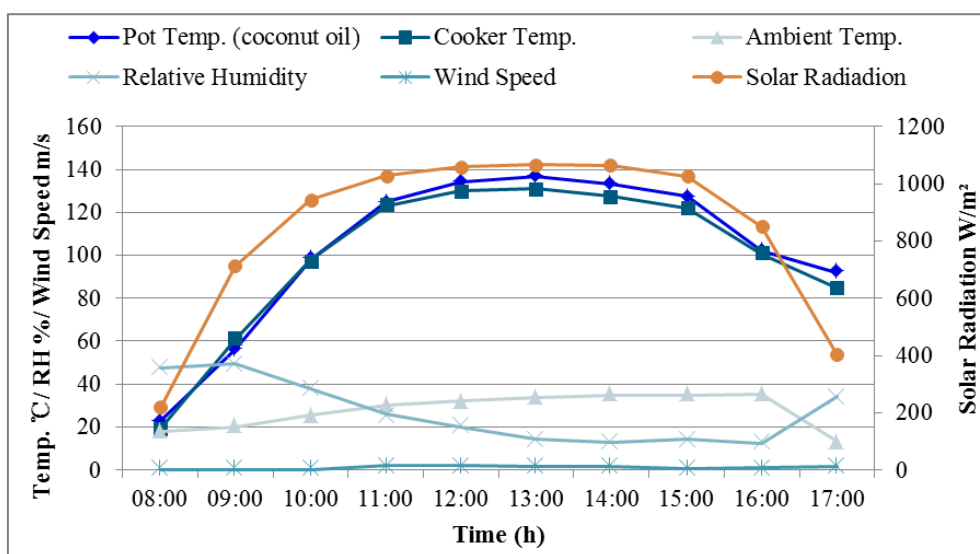


Figure 5. Thermal performance test under heating test with mustard oil.

3.4. Load Testing of Solar Cooker Using Formulated Herbal Pain Relief Oil

The performance of box type solar cooker was evaluated with load test as filling with 5% nirgundi leaves powder and 5% herbs (ajwain, fenugreek, garlic, turmeric) formulated oil for one day in container with reflector for winter are presented in Table 2. It was observed that the temperature inside the pot was found more than temperature observed in chamber inside of solar cooker which was 11.3 °C more. The maximum temperature achieved by cooker was 121 °C in winter at 14 h meanwhile the ambient temperature was 38.2 °C, humidity was 10%, 1.5m/s wind speed and 1066 W/m² solar radiation was observed. Total 500 ml mustard oil along with 125 g of mix powder of five herbal as 25 g poured in mustard oil in pot and put up it on box type solar cooker for day and day after day. It was observed that yellowish green colour was observed at end of day evaluation and 400 ml herbal pain relief oil was obtain in first filtration. It means 100 ml oil was soaked by

herbs paste. Similarly solar cooker was evaluated for 10% and 15% share of nirgundi leaves powder and rest of selected herbs in 500 ml mustard oil upto two days and all observed parameter were depicted in Table 2.

Table 2 presents a comprehensive evaluation of the performance of a box type solar cooker in the formulation of herbal pain relief oil, with varying concentrations of nirgundi leaves (5%, 10%, and 15%) combined with a consistent 5% of other herbal ingredients, over one and two days of heating. The table also juxtaposes these results with those obtained from traditional processing methods to highlight the efficacy of solar thermal technology. The evaluated parameters include thermal conditions (average, maximum, and minimum temperatures in the cooking pot), environmental factors (average humidity, wind speed, and solar radiation), and oil yield metrics (oil gain and loss in ml and %). This detailed analysis provides insights into the efficiency, quality, and viability of using solar cookers for herbal oil production.

Table 2. Comparative analysis of solar cooker performance for herbal pain relief oil formulation.

Evaluation Parameter	1 Day			2 Days		
Nirgundi	5%	10%	15%	5%	10%	15%
Rest herbs	5%	5%	5%	5%	5%	5%
Average temp. (°C) in pot	92.7	93.4	97.5	82.2	83.5	83.3
Max. temp. (°C) in pot	118.5	120	123.7	115.7	114.9	114.5
Min. temp. (°C) in pot	27.0	27.2	23.9	26.6	26.7	27.7
Average humidity,%	20.4	20.4	20.4	18.8	18.8	18.8
Average wind speed, m/s	1.3	1.3	1.3	1.2	1.2	1.2
Average solar radiation, W/m ²	882	882	882	813	813	813
Oil gain, ml (%)	400 (80%)	390 (78%)	355 (71%)	410 (82%)	390 (78%)	350 (70%)
Oil loss, ml (%)	100 (20%)	110 (22%)	145 (29%)	90 (18%)	110 (22%)	150 (30%)
Traditional Method						
Oil gain, ml (%)	400 (80%)	380 (76%)	350 (70%)			
Oil loss, ml (%)	100 (20%)	120 (24%)	150 (30%)			

On the first day, the average pot temperature ranged from 92.7 °C to 97.5 °C, with the highest temperature recorded at 123.7 °C for the 15% nirgundi formulation. The maximum temperatures were consistently higher on the first day (118.5 to 123.7 °C) compared to the second day (114.5 to 115.7 °C), likely due to sustained solar exposure and heat retention. Minimum temperatures remained relatively stable, ranging from 23.9 °C to 27.7 °C across both days, indicating consistent

thermal stability during non-heating periods. The 15% nirgundi formulation on the first day exhibited the highest average temperature (97.5 °C), suggesting optimal heat absorption for this composition. Environmental parameters, including average humidity (20.4% on day 1 and 18.8% on day 2), wind speed (1.3 m/s on day 1 and 1.2 m/s on day 2), and solar radiation (882 W/m² on day 1 and 813 W/m² on day 2), remained relatively consistent within each day. These

conditions reflect the stable solar input and ambient environment conducive to effective solar cooking.

Oil gain was highest for the 5% nirgundi formulation, yielding 400 ml (80%) on the first day and 410 ml (82%) on the second day. In contrast, the 15% nirgundi formulation resulted in lower yields of 355 ml (71%) on the first day and 350 ml (70%) on the second day, indicating that higher nirgundi concentrations may lead to increased oil loss. Oil loss ranged from 90 ml (18%) to 150 ml (30%), with the highest losses observed in the 15% nirgundi formulation (145 ml on day 1 and 150 ml on day 2). This suggests that higher herbal concentrations may contribute to greater evaporation or degradation during processing. Compared to the traditional method, the box type solar cooker demonstrated comparable oil yields, with the 5% nirgundi formulation achieving identical oil gain (400 ml, 80%) on the first day. However, the traditional method showed slightly higher losses for the 10% and 15% formulations (120 ml and 150 ml, respectively) compared to the solar cooker on the second day.

The data underscores the box type solar cooker's potential as an efficient and sustainable alternative to traditional methods for producing herbal pain relief oil. The 5% nirgundi formulation consistently delivered the highest oil yield with minimal loss, suggesting an optimal balance of herbal concentration and thermal efficiency. The slight variations in temperature and yield across the two days highlight the influence of environmental factors and processing duration on oil quality and quantity. These findings advocate for the adoption of solar thermal technology in herbal oil production, offering an eco-friendly and cost effective approach that aligns with global sustainability goals. This table provides a robust foundation for further research into optimizing herbal formulations and scaling solar based processing techniques

for pharmaceutical applications, ensuring both economic viability and environmental benefits.

3.5. Physicochemical Characterization

The physicochemical properties of herbal pain relief oil, formulated using a box type solar cooker, were evaluated for various parameters, including pH, specific gravity, viscosity, acid value, saponification value, and refractive index. The formulations comprised 5%, 10%, and 15% nirgundi leaf powder combined with a consistent 5% concentration of four additional herbs, processed over one, two, and three days. Detailed results are presented in Table 3. The pH of the formulated herbal oil ranged higher than that of commercial massage oils (5.56 to 6.01), indicating a more alkaline profile, consistent with findings by [11]. The specific gravity of the produced oil was less than 1, suggesting it remains buoyant in water, a desirable characteristic for herbal oils as noted by [13, 30]. The viscosity of the formulated oil was lower than the standard range for mustard oil (34.19 to 43.38 Pa s; [21], signifying favorable flow properties and good condition. The acid value of the herbal oil was within the acceptable limit of less than 2 mg KOH/g [13, 30], confirming its suitability for use. Similarly, the saponification value was lower than that of nirgundi oil (148.22 mg KOH/g; [14], indicating high purity and quality. The refractive index of the produced oil fell below the range for medicated oils (1.47 to 1.50); [13, 30], further validating its optimal condition. These results collectively demonstrate that the herbal pain relief oil produced using the box type solar cooker meets or exceeds established quality standards, highlighting the efficacy of solar thermal technology for sustainable and high-quality herbal oil production.

Table 3. Physicochemical analysis of herbal pain relief oil.

Treat-ment	Day	Nirgundi Leaves (NL) / Powder (P)	Herbs	pH	Specific gravity	Viscosity, Pa.s	Acid value, mg KOH/gm	Saponification value, mg KOH/g	Refractive index
T ₁	1	5% P	5%	6.97	0.87	28.72	1.07	32.73	1.36
T ₂	2	5% P	5%	7.17	0.91	29.31	1.16	31.33	1.37
T ₃	1	10% P	5%	7.50	0.91	28.40	1.40	32.73	1.37
T ₄	2	10% P	5%	7.33	0.91	28.17	1.07	32.73	1.37
T ₅	1	15% P	5%	7.03	0.91	28.58	1.16	34.13	1.38
T ₆	2	15% P	5%	7.37	0.91	28.95	1.07	31.33	1.38
T ₇	2	5% NL	5%	7.67	0.89	28.76	1.15	29.92	1.38
T ₈	2	10% NL	5%	7.57	0.91	28.21	1.07	30.39	1.37
T ₉	2	15% NL	5%	7.77	0.91	29.14	0.82	29.92	1.38
T ₁₀	Traditional method	5% NL	5%	7.47	0.89	29.45	1.40	33.19	1.38
T ₁₁		10% NL	5%	7.47	0.91	29.59	1.16	34.59	1.37

Treat-ment	Day	Nirgundi Leaves (NL) / Powder (P)	Herbs	pH	Specific gravity	Viscosity, Pa.s	Acid value, mg KOH/gm	Saponification value, mg KOH/g	Refractive index
T ₁₂		15% NL	5%	7.53	0.92	28.76	1.40	34.13	1.38
Maximum				7.77	0.92	29.59	1.40	34.59	1.38
Minimum				6.97	0.87	28.17	0.82	29.92	1.36
Mean				7.47	0.91	28.76	1.15	32.73	1.38
CV%				0.75	1.38	0.25	13.71	2.51	0.12
CD @5				0.13	0.02	0.12	0.36	1.85	0.00

3.6. Statistics Analysis of Herbal Pain Relief Oil

Physicochemical data for herbal pain-relief oil, formulated using a box-type solar cooker, were subjected to rigorous statistical analysis via an advanced online platform, with results indicating statistical significance at a 5% level. Table 4 compares the physicochemical properties of the formulated oil, prepared with 5% and 15% nirgundi powder and 15% nirgundi leaves (all evaluated on day 2), against mustard oil standards, reference pain relief oils [13, 30], and commercial products. Parameters assessed included color, odor, pH, specific gravity, viscosity, acid value, saponification value, and irritation potential. The formulated oil consistently exhibited a yellowish green color and a pungent, sharp flavor, aligning with desirable sensory characteristics. Its pH (7.4 to 7.8) was notably more neutral than commercial oils (3.75 to 5.8), while specific gravity (0.9 to 0.92) and viscosity (289.50 to 293.62 mP) fell within optimal ranges, indicating excellent physical

properties. The acid value (0.70 to 1.16 mg KOH/g) and saponification value (29.45 to 30.85 mg KOH/g) were significantly lower than reference standards, suggesting high purity and stability. Furthermore, the formulated oil was non-irritant, contrasting with the slight irritation observed in mustard oil and some reference oils. These results underscore the efficacy of box type solar cooker technology in producing superior-quality, non-irritant herbal pain-relief oil, offering a sustainable and cost effective alternative for pharmaceutical applications.

Table 4 provides a comprehensive comparison of the physicochemical properties of herbal pain relief oil formulated using a box type solar cooker, benchmarked against mustard oil, established reference ranges for pain relief oils [13, 30], and commercial products. The formulated oils, prepared with 5% nirgundi powder, 15% nirgundi powder, and 15% nirgundi leaves (all evaluated on day 2), were assessed for color, odor, pH, specific gravity, viscosity, acid value, saponification value, and irritation potential.

Table 4. Comparative physicochemical assessment of herbal pain-relief oil formulated using box type solar cooker.

Parameters	Range of mustard oil	Reference range for pain relief oil	Panchaguna taila [13]	Massage oil [30]	Formulated herbal oil in box type solar cooker (For 2 Days testing)		
					5% Nirgundi powder	15% Nirgundi powder	15% Nirgundi leaves
Colour	Reddish-Brown	Greenish Brown	Greenish Brown	Pale Brown	Yellowish Green	Yellowish Green	Yellowish Green
Odour	Pungent Sharp Flavour	Aromatic	Absent	Characteristic	Pungent Sharp Flavor	Pungent Sharp Flavor	Pungent Sharp Flavor
pH Value	4.73 +/- 0.14	3.83-4.08	3.75	5.8	7.6	7.4	7.8
Specific Gravity	0.910	0.9581-0.9613	0.9106-0.9259	0.90 +/- 0.02	0.9	0.92	0.9
Viscosity (milipoise -mp)	117.27 mp	289 mp	Absent	Absent	293.62	289.50	290.87
Acid Value (mg KOH/g)	1.12 +/-0.04	2.171-3.384	2.02	0.651 +/- 0.005	1.16	0.93	0.70

Parameters	Range of mustard oil	Reference range for pain relief oil	Panchaguna taila [13]	Massage oil [30]	Formulated herbal oil in box type solar cooker (For 2 Days testing)		
					5% Nirgundi powder	15% Nirgundi powder	15% Nirgundi leaves
Saponification Value (mg KOH/g)	125.6	186.155-188.240	160-184	186 +/- 0.05	30.85	30.85	29.45
Irritation	Slightly Irritation	Slightly Irritation	Non-Irritant	No Irritation	No Irritation	No Irritation	No Irritation

The formulated oils exhibited a consistent yellowish green color, distinct from the reddish brown of mustard oil, greenish brown of reference oils, and pale brown of massage oil. This vibrant hue suggests high quality extraction and preservation of herbal pigments. The odor was characterized as a pungent, sharp flavor across all formulated oils, aligning with mustard oil but differing from the aromatic or absent odors of reference and commercial oils, indicating a robust herbal profile. The data in Table 4 highlight the superior quality of the herbal pain relief oil produced using a box type solar cooker, particularly in terms of neutral pH, low acid and saponification values, and non-irritant properties. These attributes position the formulated oil as a competitive alternative to commercial products, with the added benefit of sustainable production via solar thermal technology. The statistical significance at a 5% level further validates the reliability of these findings, supporting the adoption of box type solar cookers for eco-friendly, high quality herbal oil production in pharmaceutical contexts.

The formulated oils demonstrated pH values ranging from 7.4 to 7.8, significantly more neutral than mustard oil (4.73 ± 0.14), reference oils (3.83 to 4.08), Panchaguna Taila (3.75), and massage oil (5.8). This near-neutral pH enhances skin compatibility and stability. The specific gravity of the formulated oils (0.9 to 0.92) was comparable to mustard oil

(0.910) and massage oil (0.90 ± 0.02), and slightly lower than reference ranges (0.9581 to 0.9613 and 0.9106 to 0.9259). These values indicate that the formulated oils are buoyant in water, a desirable trait for topical applications. Viscosity for the formulated oils ranged from 289.50 to 293.62 mP, closely aligning with the reference value (289 mP) and exceeding that of mustard oil (117.27 mP). The absence of viscosity data for commercial oils highlights the formulated oils' favorable flow properties, suitable for massage applications. The acid value of the formulated oils (0.70 to 1.16 mg KOH/g) was well below the reference range (2.171 to 3.384 mg KOH/g) and comparable to or lower than mustard oil (1.12 ± 0.04), Panchaguna Taila (2.02), and massage oil (0.651 ± 0.005). This indicates high stability and low free fatty acid content, enhancing shelf life. The saponification value of the formulated oils (29.45 to 30.85 mg KOH/g) was substantially lower than mustard oil (125.6 mg KOH/g), reference ranges (160 to 188.240 mg KOH/g), and commercial oils (186 ± 0.05 mg KOH/g). This suggests a lower molecular weight of fatty acids, indicative of high purity. Unlike mustard oil and reference oils, which exhibited slight irritation, the formulated oils were non-irritant, matching the non-irritant properties of commercial oils. This underscores their suitability for sensitive skin applications.

3.7. Sensory Evaluation of Herbal Pain Relief Oil

Table 5. Sensory evaluation of herbal pain relief oil.

Treatment	Colour	Odour	Sensitivity	Irritation	Overall Acceptability
T ₁	8.0	6.3	6.7	7.0	7.0
T ₂	7.7	7.0	8.0	8.3	7.8
T ₃	7.0	7.0	7.0	8.0	7.3
T ₄	8.0	7.0	7.7	7.0	7.4
T ₅	8.0	8.3	8.0	7.0	7.9
T ₆	8.0	7.0	7.7	9.0	7.9
T ₇	7.0	6.0	7.0	8.0	7.0

Treatment	Colour	Odour	Sensitivity	Irritation	Overall Acceptability
T ₈	8.0	8.0	7.0	7.0	7.5
T ₉	8.0	8.0	8.0	8.0	8.0
T ₁₀	7.0	6.0	7.0	6.0	6.5
T ₁₁	6.3	6.0	7.0	6.3	6.4
T ₁₂	8.7	8.0	8.0	7.7	8.1
Maximum	8.7	8.3	8.0	9.0	8.1
Minimum	6.3	6.0	6.7	6.0	6.4
Mean	8.0	7.0	7.3	7.3	7.5
CV%	3.8	3.3	3.9	3.9	1.8
CD@5	0.5	0.4	0.5	0.5	0.2

A sensory evaluation of herbal pain relief oil was conducted by a panel of 18 trained panelists, who assessed the oil's quality based on color, odor, sensitivity, irritation, and overall acceptability, using a 9-point scoring scale. The findings indicate that treatment T₆ for herbal hair oil and treatments T₆ and T₉ for herbal pain relief oil exhibited superior sensory attributes compared to other formulations. Statistical analysis of the physicochemical and sensory data, processed through an advanced online statistical platform, confirmed that the treatments were statistically significant at a 5% level of significance. These results underscore the efficacy of the box type solar cooker in producing high quality herbal pain relief oil with favorable sensory characteristics, offering a sustainable and effective solution for pharmaceutical applications.

Table 5 provides a comprehensive overview of the sensory attributes of herbal pain relief oil across 12 treatments (T₁ to T₁₂), as assessed by a panel of 18 trained panelists. The evaluation criteria included color, odor, sensitivity, irritation, and overall acceptability, each scored on a 9-point hedonic scale, where higher scores indicate better sensory quality. The table also includes statistical metrics such as maximum, minimum, mean, CV%, and critical difference at 5% significance (CD@5), providing a robust analysis of the sensory performance of the formulated oils.

Colour scores ranged from 6.3 (T₁₁) to 8.7 (T₁₂), with a mean of 8.0, indicating generally high visual appeal. Treatment T₁₂ achieved the highest score, suggesting an optimal yellowish-green hue, a desirable trait for herbal oils. The low CV% (3.8) and CD@5 (0.5) reflect consistent color perception across treatments. Odor scores varied from 6.0 (T₇, T₁₀, T₁₁) to 8.3 (T₅), with a mean of 7.0. Treatment T₅'s high score indicates a particularly favorable pungent, sharp flavor, aligning with consumer preferences for herbal oils. The CV% (3.3) and CD@5 (0.4) suggest minimal variability in odor perception. Sensitivity scores, reflecting skin compatibility, ranged from 6.7 (T₁) to 8.0 (T₂, T₅, T₉, T₁₂), with a mean of 7.3.

The high scores for T₂, T₅, T₉ and T₁₂ indicate excellent tactile properties, with low variability (CV% = 3.9, CD@5 = 0.5). Irritation scores, assessing skin tolerance, ranged from 6.0 (T₁₀) to 9.0 (T₆), with a mean of 7.3. Treatment T₆'s perfect score of 9.0 highlights its non-irritant nature, a critical factor for topical applications. The CV% (3.9) and CD@5 (0.5) indicate consistent panelist agreement. Overall acceptability scores ranged from 6.4 (T₁₁) to 8.1 (T₁₂), with a mean of 7.5. Treatment T₁₂ achieved the highest score, reflecting superior sensory performance across all parameters. The notably low CV% (1.8) and CD@5 (0.2) suggest high reliability and consistency in overall acceptability.

The low CV% values (1.8 to 3.9) across all parameters indicate minimal variation in panelist responses, reinforcing the reliability of the sensory evaluation. The CD@5 values (0.2 to 0.5) confirm that differences between treatments are statistically significant at the 5% level, validating the distinct sensory profiles of the formulations. Treatments T₆, T₉, and T₁₂ consistently scored high across multiple parameters, with T₆ excelling in irritation (9.0) and T₁₂ leading in color (8.7) and overall acceptability (8.1). These treatments likely represent the optimal formulations for consumer preference. The sensory evaluation data in Table 5 demonstrate the superior quality of the herbal pain relief oil produced using a box type solar cooker, particularly for treatments T₆ and T₁₂, which exhibit exceptional sensory attributes. The non-irritant nature, vibrant color, and favorable odor profile of these formulations enhance their suitability for pharmaceutical applications. The statistical significance at the 5% level further validates the reliability of these findings, supporting the adoption of solar thermal technology as a sustainable, efficient, and consumer-preferred method for producing high-quality herbal oils. These results provide a strong foundation for further optimization and commercialization of solar-processed herbal pain-relief oils.

3.8. Economic Analysis of Herbal Pain Relief Oil

The economic viability of producing herbal pain relief oil using a box type solar cooker was assessed by analyzing the input costs of herbal ingredients, including mustard oil and varying concentrations of nirgundi powder (5:5, 10:5, and 15:5 ratios with other herbs), across different processing methods. The results, detailed in Tables 6, 7 and 8, reveal variations in production costs influenced by differences in oil recovery rates and extraction efficiencies. Statistical analysis confirmed that the cost differences were significant at a 5% level, highlighting the cost-effectiveness of the solar cooker method. Compared to commercially available pain relief oils, the formulated oil demonstrated competitive pricing, underscoring the potential of solar thermal technology as a sustainable and economically advantageous approach for producing high quality herbal oils in pharmaceutical applications.

Table 6 outlines the costs associated with producing 500 ml of herbal pain relief oil using varying concentrations of nirgundi powder (5%, 10%, and 15%) combined with a fixed 5% of other herbs (ajwain, fenugreek, turmeric powder, and garlic). The costs are calculated for two days of processing. Higher nirgundi concentrations increased raw material costs, with the 15:5% formulations being the most expensive. Day 2 costs were consistently higher due to doubled labor expenses, indicating that single-day processing may be more cost-efficient. Table 7 adjusts production costs based on oil recovery rates and compares the formulated oil's selling price with market-available products. The 5:5% formulations

yielded the highest recovery (410 ml on Day 2), while the 15:5% formulation had the lowest (350 ml on Day 2). Lower recovery rates in higher nirgundi concentrations likely result from increased herbal mass affecting extraction efficiency. Production costs per 500 ml, adjusted for recovery, ranged from ₹337.8 (5:5%, Day 1) to ₹618.2 (15:5%, Day 2). Lower recovery rates increased per unit costs, particularly for the 15:5% formulation. Selling costs, including a 10% profit margin, ranged from ₹371.6 (5:5%, Day 1) to ₹618.2 (15:5%, Day 2). The formulated oil's selling cost per 100 ml was significantly lower than commercial products: ₹99.3 (5% nirgundi, Day 2) and ₹123.4 (15% nirgundi, Day 2) compared to ₹263 for Dr. Ortho pain-relief oil and ₹220 for IMC Ayurvedic Herbal Pain Away oil. This competitive pricing highlights the economic advantage of the solar cooker method, particularly for the 5:5% formulations on Day 2.

The statistical significance at the 5% level confirms that variations in costs and recovery rates across treatments are meaningful, reflecting the impact of formulation and processing duration. The 5:5% formulation on Day 2 offers the best balance of high recovery (82%) and low production cost (₹ 451.5), resulting in a competitive selling price of ₹ 99.3 per 100 ml. These findings demonstrate the economic feasibility of using box-type solar cookers for herbal oil production, offering a sustainable alternative to conventional methods while maintaining cost-effectiveness and market competitiveness. The data provide a strong foundation for scaling up solar-based production processes in the pharmaceutical industry.

Table 6. Input cost (₹.) for producing herbal pain relief oil.

Method (Nirgundi: Rest Herbs)		5:5%		5:10%		5:15%	
Material	Market Prize ₹/kg	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2
Mustard oil	200.0	100.0	100.0	100.0	100.0	100.0	100.0
Nirgundi powder	1250.0	31.3	31.3	62.5	62.5	93.8	93.8
Ajwain	720.0	18.0	18.0	18.0	18.0	18.0	18.0
Fenugreek	200.0	5.0	5.0	5.0	5.0	5.0	5.0
Turmeric powder	400.0	10.0	10.0	10.0	10.0	10.0	10.0
Garlic	240.0	6.0	6.0	6.0	6.0	6.0	6.0
Labour cost	100.0	100.0	200.0	100.0	200.0	100.0	200.0
Total production cost	-	270.2	370.2	301.5	401.5	332.7	432.7
Profit (10% of production cost)	-	27.0	37.0	30.2	40.2	33.3	43.3
Selling Cost (500 ml)	-	297.2	407.2	331.6	441.6	366.0	476.0

Table 7. Production costs (₹.) of herbal pain relief oil based on recovery.

Treatment (Nirgundi: Rest herbs)	5:5%		10:5%		15:5%	
Day	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2
Oil recovery (%)	80.0	82.0	78.0	78.0	71.0	70.0
Oil recovery (ml)	400.0	410.0	390.0	390.0	355.0	350.0
Total production cost (₹.)	337.8	451.5	386.5	514.7	468.7	618.2
Profit (10% of production cost) (₹.)	33.8	45.2	38.7	51.8	46.9	61.8
Selling cost for 500 ml oil (₹.)	371.6	496.7	425.2	566.2	515.5	618.2

Table 8. Comparison with suitable market pain relief oil (Price ₹./100 ml).

Market available oil		Formulated herbal pain relief oil	
Dr. Ortho pain relief oil	IMC ayurvedic herbal pain away oil	5% Nirgundi powder Day 2	15% Nirgundi powder Day 2
₹. 263	₹. 220	₹. 99.3	₹. 123.4

4. Conclusions

The investigation revealed that the box type solar cooker achieved optimal thermal performance, attaining peak temperatures of 127.4 and 122.7 °C under solar radiation levels of 840.3 and 854.6 W/m² respectively, with corresponding wind speeds of 1.2 and 2.22 m/s. The formulated herbal oil, prepared with 15% nirgundi leaves and 5% additional ingredients over two consecutive days of heating, exhibited favorable physico-chemical properties, including a pH of 7.8, acid value of 0.70 mg KOH/g, specific gravity of 0.92, viscosity of 29.09 Pa s, saponification value of 29.45 mg KOH/g, and refractive index of 1.38. Notably, the herbal oil displayed an optimal yellowish green hue, indicating superior quality among the evaluated parameters. The adoption of box type solar thermal technology for producing herbal pain relief oil demonstrated significant economic viability, yielding a profit margin of ₹50 to 60 per liter. These findings underscore the efficacy and sustainability of solar thermal technology in the production of high quality herbal formulations, offering a promising avenue for scalable, eco-friendly processing in pharmaceutical applications.

Abbreviations

REE	Renewable Energy Engineering
CAET	College of Agricultural Engineering and Technology
NAU	Navsari Agricultural University

ICAR	Indian Council of Agricultural Research
CD	Critical Difference
CV	Coefficient of Variation
F ₁	First Figure of Merits
F ₂	Second Figure of Merits
IMC	International Marketing Corporation Pvt. Ltd., Ludhiana

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Author Contributions

Sandip Sengar: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft

Tilak Chavda: Methodology, Resources, Visualization, Writing – original draft

Alok Singh: Data curation, Formal Analysis, Investigation, Methodology, Resources, Supervision, Validation, Visualization, Writing – review & editing

Jay Chaudhari: Data curation, Formal Analysis, Investigation, Methodology, Supervision, Visualization, Writing –

original draft

Bhautik Mishra: Data curation, Formal Analysis, Investigation, Methodology, Supervision, Visualization, Writing – original draft

Conflicts of Interest

The authors declare no conflicts of interest.

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