

Empirical Relation to Predict Essential Oil Yield in Conventional Distillation System

Ravi Kant¹, Anil Kumar^{2,*}

Abstract

Peppermint is medicinal herb, and its extracts (essential oils) are of great importance because they are used in pharmaceutical, food, and cosmetic items. Moreover, peppermint oil is also used as anti-cancer, anti-bacterial, anti-viral, spasmodic, anti-diabetic, ulcer healing, anti-obesity, etc. Steam distillation method is used to extract essential oil from peppermint. Boiler, extraction unit, condenser and Florentine flask are the main components of steam distillation system. The objective of present study is to develop a linear relationship for predicting peppermint essential oil yield using a regression model. Peppermint batch size was used as an input variable in linear regression model based on simple correlation analysis. Furthermore, operational performance parameters such as productivity and essential oil yield are determined in this study. Experiments were performed for different batch sizes of peppermint (1000 to 2000 kg) for 5 days. Higher productivity and essential oil yield are obtained for higher batch sizes of peppermint. Productivity and EOY increased from 9 to 19 kg and 0.9 to 0.94% (w/w) with increasing batch size from 1000 to 2000 kg, respectively. Results showed that linear relation of batch size of peppermint with yield was obtained based on the performance of Pearson's coefficient and regression coefficient ($Adj-R^2$). Pearson coefficient and $Adj-R^2$ were obtained as 0.99516 and 0.99016. The Pearson and regression coefficient values show that the regression model provided a better correlated output for yield of peppermint. Developed empirical relation provides a powerful tool for investigating the relationship between essential oil yield (output variable) and batch size of peppermint (input variable).

INTRODUCTION

Most of the people worldwide (80%) use herbal remedies to treat their health problems. The extract of aromatic and medicinal plants is used to produce herbal medications. According to records kept by the WHO, some 21000 species are used as medicinal plants. Distillation is used to extract essential oils from medicinal plants [1–3]. Essential oils are utilised as a flavour in food industry, as a scent in cosmetic industry, and in medicine for functional purposes [3, 4]. Peppermint (*Mentha peperita* L) belongs to *Lamiaceae* (*Labiatae*) family of medicinal herbs that grows in the summer and rainy seasons. It is a native species of Mediterranean region that is grown worldwide for flavouring, aroma, medicinal, and pharmaceutical applications [5].

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It is commonly used to treat digestive disorders and neurological systems. Peppermint is grown in areas where the soil has a lot of water storage capacity. Underground rootstocks, produced by existing plants are used to grow all commercial peppermint varieties. The rootstocks are formed up of plants that already exist. Rootstock cannot be stored for more than a few days due to quick deterioration due to heat and dryness [6]. Menthone and menthol are peppermint oil's (PO) two main components. Its chemical composition changes according to the location, plant growth, and processing conditions [7]. Figure 1 represents



Figure 1. Peppermint oil used in pharmaceutical industry as health benefits.

various applications of peppermint oil in pharmaceutical industry. Various methods are used for peppermint oil extraction, such as steam distillation [1], hydro-distillation [7], solvent extraction, supercritical fluid extraction [8], and subcritical extraction liquid [9]. Most widely used method is steam distillation (SD) or hydro-distillation (HD) [10]. In SD, water steam is utilized to vaporise the oil from leaves and vaporised oil and water mixture is subsequently condensed in the condenser.

Many engineering and scientific problems require studying or assessing the relationship between two or more variables. Moreover, many situations exist where the relationship between variables is not deterministic. "Regression Analysis" refers to statistical tool used to model and investigate non-deterministic relationships between variables. It is one of the most regularly used statistical tools since issues of this type frequently occur in many engineering and research fields [11].

Gago *et al.* compared ANNs technology to traditional statistical analysis to determine its applicability as an alternative methodology in plant research [12]. Niazian *et al.* used two approaches: multiple regression model (MLR) and artificial neural network (ANN), to determine ajowan oil content from easily observable plant features [13]. With a root mean square error (RMSE) of 0.192%, determination coefficient (R^2) of 0.901 and mean absolute error (MAE) of 0.112%, the ajowan oil content was well predicted using the Sigmoid Axon transfer function and two hidden layers of an ANN. Performance of ANN was better than multiple linear regression (MLR) in terms of RSME and R^2 [13].

Various studies have been performed on developing linear empirical relations between dependent and independent variables for seeds and aromatic crops using regression analysis. In this study, empirical models are developed relating yield to batch size of peppermint. Statistical analysis was performed to develop empirical relation between two variables using regression analysis. It would be helpful to farmers in deciding the size and investment in peppermint oil extraction plant.

MATERIAL AND METHOD

Conventional steam distillation system (CSD) is established at Birpura village, Jhansi, India (25°36'N 18.40"E). In November 2021, experiments were conducted for one full cycle over 5 days for various batch sizes (1000 to 2000 kg) across the entire plant.

Table 1. Parameters of Peppermint plant [2].

S.N.	Properties	Units	Values
1.	Diameter of stem	mm	2.37
2.	Length of stem	cm	15–20
3.	Number of leaves per plant	–	20–40
4.	Moisture content of leaves	%	83.52
5.	Mass of plant	g	3–5
6.	Thickness of leaves	mm	0.25

Sample Preparation

Peppermint plants are grown in soil that has high water storage capacity. Various properties of peppermint plants are depicted in Table 1. Some weeds are grown in the field of peppermint after irrigation; therefore, In order to decrease weeds in field, panida herbicide is sprayed. Spraying mentha power and urea fertilizer on the crop promotes peppermint plant growth and increases oil content. Around India, this crop is often harvested in November. After being harvested with farm equipment, peppermint leaves are collected and transported by tractor from field to the distillation plant. Plants for mint are weighed using a computerized machine. After being weighed, peppermint plants are delivered by a conveyor in distillation unit.

Distillation System

A conventional distillation system (CSD) consists of furnace, boiler, distillation unit, and condenser. Experiments were conducted for different batch sizes and were repeated for 5 days for same batch size.

Furnace: Furnace was made up of bricks and concrete. Furnace was cuboid in shape, 1.82 m in length, 2.27 m in width, and 0.076 m in height. Heat is generated in the furnace by burning biomass (wood), which is transferred to the boiler.

Boiler: It was made up of iron with length of 2.13 m, width of 2.13 m and height of 0.063 m. Evaporation of water is completed in boiler. Steam is produced when the water in the boiler reaches its boiling point. Around 300–500 l water is required to complete one cycle. It is placed above the furnace.

Distillery: The distillery was made to handle enough peppermint plant batch sizes. Extraction unit was cylindrical, with a diameter of 1.82 m and a height of 3.04 m. It is constructed of stainless steel with a thickness of 2 cm. Two nets with a 1.80 m diameter were placed inside the extraction unit, one at the bottom and the other at mid-height from the bottom, to place peppermint plants batch and allow steam to separate volatile oil easily. Distillery includes two openings: one at bottom to supply steam from the boiler to the distillery, which passes inside peppermint plants to separate volatile oil, and another at the top to supply steam from essential oil to the condenser to separate oil.

Condenser: It was made up of stainless steel with 2.13 m length, 1.52 m width, and 1.52 m height. Steam intake, cooling water inlet, condensed water outlet and cooling water outlet were the four openings on the condenser. Cooling water was delivered to the condenser unit via a water tank controlled by a hand valve. It was also connected to the extraction unit, which received steam and oil, which was then condensed to generate volatile oil. A funnel tube was used to collect the volatile oil that had been extracted. Oil floats to the top because oil is less dense than water. Figure 2 depicts the schematic setup for CSD system.

EXPERIMENTAL OBSERVATIONS

In November 2021, experiments were conducted for one complete cycle for different batch sizes of the entire plant (1000 to 2000 kg) for 5 days. Studies were conducted from 03:00 to 08:00 pm (5 h)

for each day. Digital temperature indicator and thermocouples were used to record temperatures at various points in the boiler and extracting unit. The mass of wood fuel was weighed using a digital weighing machine, and oil production was measured using a beaker with a measuring scale marked on the upper side.

Essential Oil Yield (EOY)

EOY is defined as mass of oil extracted per mass of plant batch size. It can be calculated as [2, 14]:

$$\text{EOY} = \frac{\text{Mass of oil extrated}}{\text{Mass of plant batch size}} \quad (1)$$

RESULT AND DISCUSSION

Essential Oil Yield

Essential oil yield (EOY) for different batch sizes of peppermint has been depicted in Figure 3. Result showed that the maximum essential oil yield was 0.94% (w/w) for batch sizes of 2000 kg. EOY was increased from 0.9 to 0.94% (w/w) with increasing batch size from 1000 to 2000 kg, respectively. The increase of EOY by increasing peppermint plant batch size was due to the extraction of majority of volatile oil, particularly in larger batch sizes.

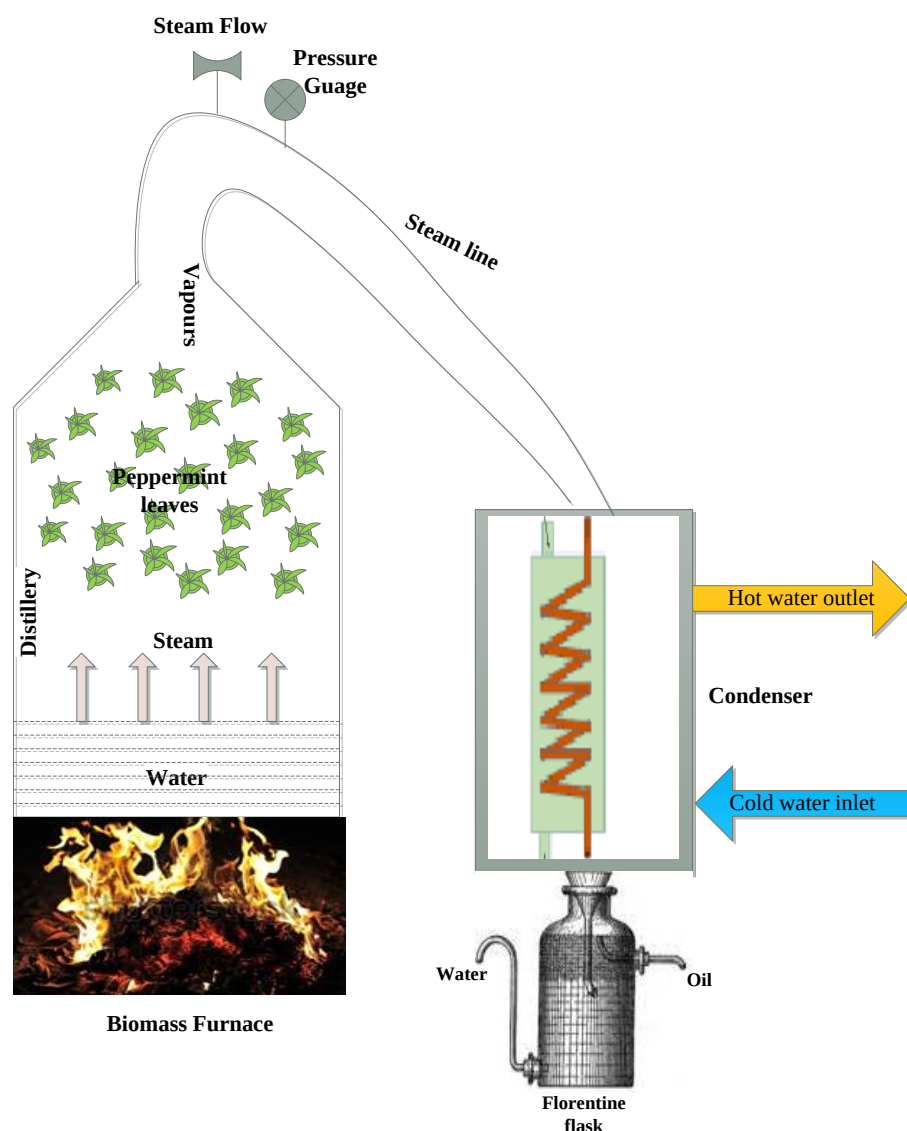


Figure 2. Conventional distillation system.

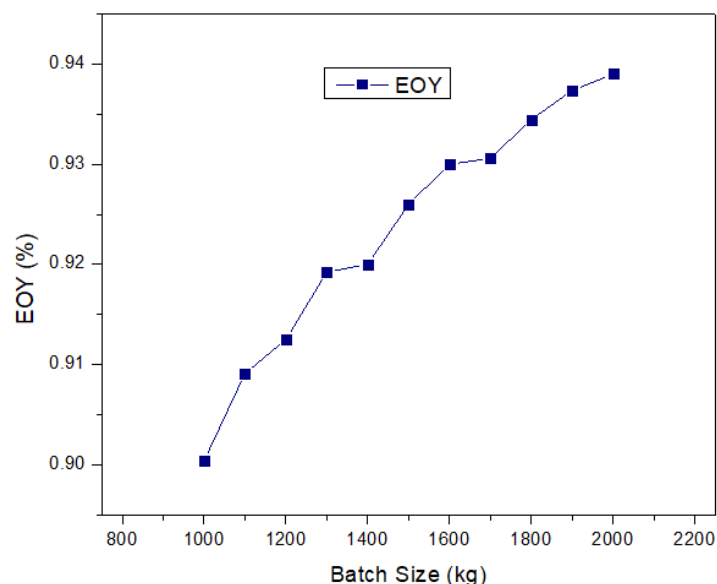


Figure 3 Variation in essential oil yield with batch size of peppermint.

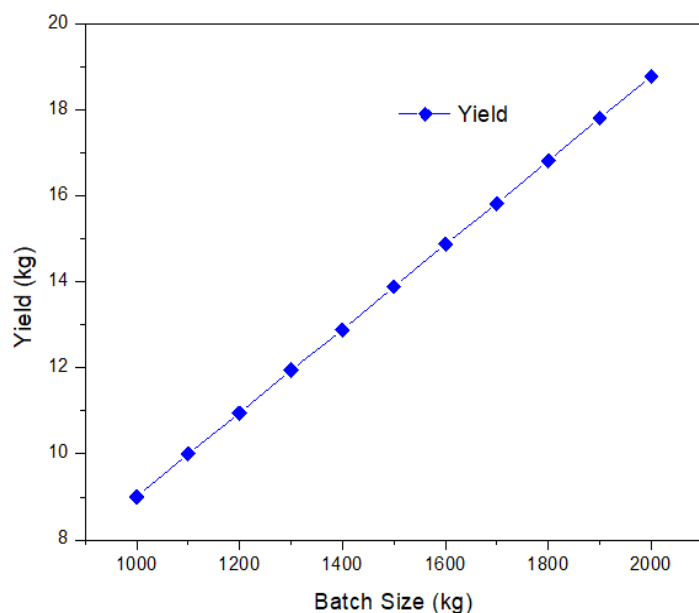


Figure 4. Variation in yield with batch size of peppermint.

Productivity of System

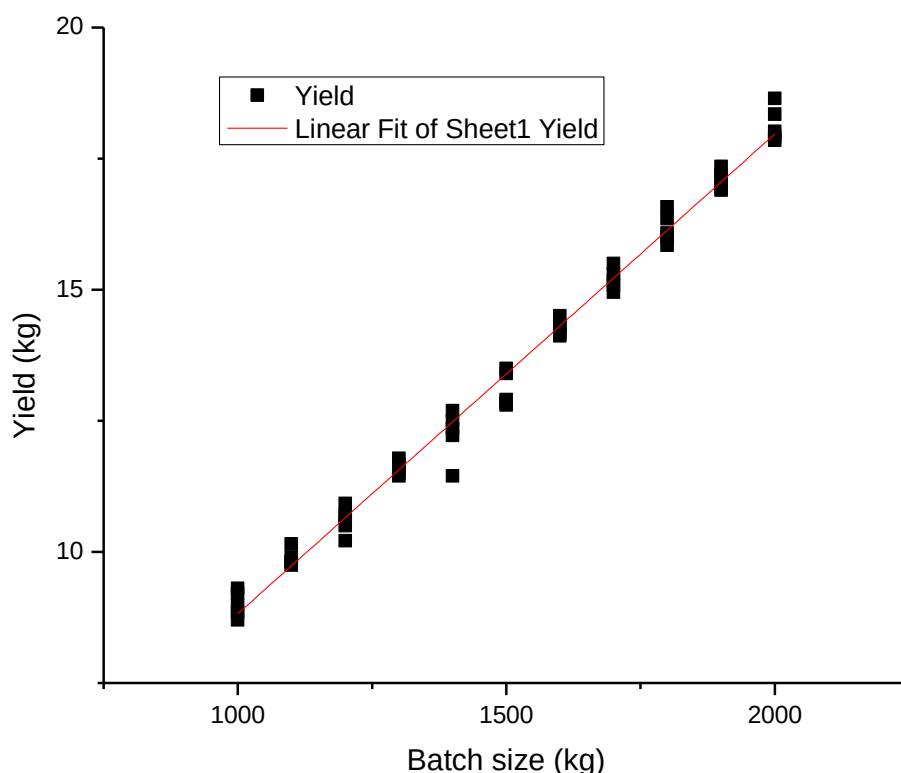
As illustrated in Figure 4, the system's yield was affected by batch size during the experimentation. Results explained that the yield increased from 9 to 19 kg by increasing batch size from 1000 to 2000 kg. Observed data indicated that maximum system productivity of 19 kg was achieved for a batch size of 2000 kg. It indicates that productivity increases with increase in batch sizes.

Linear Regression

A regression study was performed using Origin Pro 8.5 software to obtain a linear regression model for essential oil yield of peppermint. Batch size of peppermint was taken as input variable and yield as output variable. Linear relationship is obtained between input and output variables, as shown in Figure 5. The yield of peppermint is increasing with the increase in batch size. Summary of linear regression is given in Table 2. Linear relationship between batch size and yield developed by origin pro 8.5 is expressed as:

Table 2. Summary of linear regression.

	Intercepts		Slopes		Statics	
	Value	Standard error	Value	Standard error	Adj-R ²	Pearson coefficient
Yield	-0.32636	0.19024	0.00915	1.24097E-4	0.99016	0.99516

**Figure 5.** Developed empirical relation between yield and batch size.

$$Y = a + b \times X \quad (2)$$

In Eq. (2), Y, X, a, and b represent yield, batch size, intercept, and slope, respectively.

Linear relation of batch size of peppermint with yield was obtained based on the performance of Pearson's coefficient and regression coefficient (Adj-R²). Pearson coefficient (0.99516) and Adj-R² (0.99016) values show that regression model provided a better correlated output for yield of peppermint. Slope and intercept values for Eq. (2) are 0.00915 and -0.32636, respectively, as depicted in Table 2. Therefore, Eq. (2) can be rewritten as:

$$Y = -0.32636 + 0.00915 \times X \quad (3)$$

CONCLUSION

Linear regression model was applied to predict peppermint oil yield in present study. A regression model effectively trained the relationship between input variables (batch size) and output parameters (peppermint oil yield). Based on the findings, the following conclusions have been made.

- Maximum essential oil yield was obtained as 0.94% (w/w) for batch sizes of 2000 kg.
- EOY was increased from 0.9 to 0.94% (w/w) with increasing batch size from 1000 to 2000 kg, respectively.
- Productivity was increased from 9 to 19 kg by increasing batch size from 1000 to 2000 kg, respectively.
- Productivity and EOY were increasing with an increase in batch size.
- Regression coefficient (Adj-R²) for linear regression model was 0.99016.

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