Extended Essay

Chemistry

Title: Investigation of the saponification values and foaming heights of different oils

Research Question: How does the oil type (St. John's wort oil, bay seed oil, olive oil, cottonseed oil, magnesium oil, coconut oil, lanolin) affect the saponification value and foaming height of soap by titrating the oils with 0.500 mol dm^{-3} HCl at room temperature and pressure?

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Introduction: Fats and oils are called triglycerides because they are esters composed of three fatty acid units joined to glycerol, a trihydroxy alcohol ("17.2"):

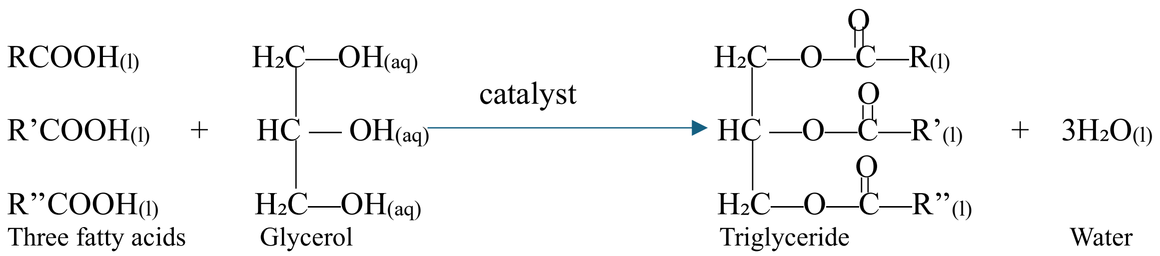


Figure 1: Shows the reaction of formation of triglycerides and water by fatty acids and glycerol

A triglyceride is called a fat if it is a solid at 25°C; it is called an oil if it is a liquid at that temperature. These differences in melting points reflect differences in the degree of unsaturation and number of carbon atoms in the constituent fatty acids. Triglycerides obtained from animal sources are usually solids, while those of plant origin are generally oils.

There are three main categories of fats, which are made up of carbon, hydrogen and oxygen molecules which are, saturated fats, unsaturated fats, and trans fats. Saturated fats are saturated with hydrogen molecules and contain only single bonds between carbon molecules ("What Is Saturated Fat and Is It Unhealthy?"). On the other hand, unsaturated fats have at least one double bond between carbon molecules.

Saponification is the process of converting fats or oils into glycerol and soap by reacting with alkalis such as potassium or sodium hydroxide. This process is crucial for understanding the chemical makeup of soap and its applications.

Saponification value, the number of milligrams of potassium hydroxide (KOH) or sodium hydroxide (NaOH) required to saponify one gram of fat under specific conditions

("Manual_Oil_Fat_25_05_2016"). Saponification value is a measure of the average molecular weight of all the fatty acids present in the form of triglycerides. The higher the saponification value, the lighter the fatty acids average molecular weight. Also, fats or oils that have higher saponification value are more suitable for soap making, because oils with higher saponification values are rich in terms of short-chain and medium-chain fatty acids, these fatty acids are more soluble in water, create a harder and cleansing soap, foam better and may remove oils from skin more effectively. On the other hand, oils that have lower saponification values have longer fatty acid chains, which are less soluble in water. Soaps that are made from oils that have lower saponification values produce softer, less cleansing soaps. The saponification value is integral into soap making, saponification value affects the hardness, quality, lathering ability and moisturizing properties of soaps.

In the article of "Rapid and Direct Iodine Value and Saponification Number Determination of Fats and Oils by Attenuated Total Reflectance/Fourier Transform Infrared Spectroscopy", rapid and reproducible method of determining the iodine value (IV) and saponification number (SN) for fats and oils was developed with an attenuated total refletance/Fourier transform infrared spectrometer (van de Voort et al.). In this investigation titration method is used instead of infrared spectrometer because, infrared spectroscopy can detect functional groups but peak intensities can overlap and vary with oil composition so it cannot be converted reliably to an unique saponification value. Also, the method of titration which is selected for this investigation is more affordable compared to infrared spectroscopy.

Fats and oils from a wide variety of sources have importance to the food industry and other industrial sectors. In almost every situation, the general characterization of such oils and the monitoring of modifications they may undergo during processing are important relative to their quality, functionality and economic value. Typical analyses that are important include iodine value (degree of unsaturation), saponification number (average molecular weight), moisture content, level of trans fatty acids, free fatty acids, peroxide value and 2-thiobarbituric acid (TBA) number. Iodine value (IV) and saponification number (SN) are two of the more common analyses used for characterizing fats and oils, with IV being crucial in monitoring hydrogenation processes.

In another article “Saponification Process and Soap Chemistry” which is written by Benedict Nnachi Alum, the types of fatty acids in fats or oils determine the properties of the soap that produces (Alum and Extension). The varieties of fatty acids in oils and how they affect the qualities of soap enable the soap maker to create oils that address a variety of consumer needs and desires, such as cleansing, moisturising, sensory, and skin concerns. Also, in this article the factors affecting the soap quality are discussed. In order to have a good cleansing and hard soap an oil with medium chain length fatty acid will be favoured. For a gentle and moisturising soap an oil with higher unsaturated fatty acid content will be favoured. Aside from fatty acid makeup, other factors influencing soap quality. Alum include temperature, mixing, curing, and additions. Not only does saponification serve hygienic purposes, but it also facilitates the production of glycerol, a valuable product in various sectors. This makes saponification both environmentally and economically advantageous. The method that will be used in this experiment aims to find the saponification values of different oils, the saponification values of these oils will be found by performing titration. The indicator that will be used in this experiment is phenolphthalein. The reason for choosing phenolphthalein is because it is an organic indicator, and it has an sharp endpoint. Phenolphthalein provides a distinct endpoint, with sudden appearance and disappearance of the colour pink.

Variable Type	Description
Dependent variable	Volume of HCl is used to calculate the saponification values of oils.
Independent variable	St. John's wort oil, bay seed oil, olive oil, cottonseed oil, magnesium oil, coconut oil, lanolin

Table 1: Dependent and Independent variables

Controlled Variables	How It Is Controlled
Concentration of HCl	0.500 mol dm^{-3} HCl used, to make the experiment with same standards for all oil types. It would not be possible to observe variations to the independent variable alone because changes in acid concentration would have a direct impact on the reaction rate and product yield.
Number of drops of indicator	5 drops of indicator, by controlling the number of drops it will be possible to maintain consistent colour intensity at the endpoint for each oil titration process.
Time of duration	Waiting time is 30 minutes, waiting time affects the temperature and heat lost or gained so it should be controlled.
Amount of oils used	Amount of oil used for every trial is approximately 5 grams, to calculate and compare the saponification value of all trials for each oil types the amount used should be consistent.
Temperature and pressure	All experiments are done in the same environment, to obtain more consistent values for all oil types the environment that the experiment done should be same. Controlled by using water bath and thermometer.
Ethanolic KOH	4% by mass KOH solution is used, to make the experiment same for all oil types.

Table 2: Controlled Variables

Materials	Quantity
Distillation unit	7
100 cm^3 measuring cylinder ± 1 cm^3	2
500 cm^3 beaker ± 5 cm^3	4
Soap mold	1
Heating plate	7
Glass rod	7
Thermometer ± 1°C	7
Clamp and stand	1
Pipette	7
Digital balance ± 0.01g	1
Phenolphthalein	5x7x3 drops
Parafilm	1
50 cm^3 Burette ± 0.1 cm^3	1
Magnetic stirrers	7
Magnetic stir with bar retriever	1
Spatula	1
Lab Coat	1
Safety goggles	1
Gloves	1
Ethanolic KOH	%4 by mass, 500 cm^3
HCl	0.500 mol dm^{-3}, 500 cm^3
Ruler ± 0.5 cm	1
Olive oil	50 ±0.01g
Cottonseed oil	50 ±0.01g
St. John's Wort oil	50 ±0.01g
Bay seed oil	50 ±0.01g
Magnesium oil	50 ±0.01g
Coconut oil	50 ±0.01g
Lanolin	50 ±0.01g

Table 3: Chemicals and equipment's

*Wear gloves, goggles, and lab coat during the experiment.

Chemical	**Hazard**	**Precaution**
Ethanolic KOH	Can irritate and burn the skin and eyes leading to eye damage.	Avoid release to the environment. *
HCl	Corrosive to the eyes, skin, and mucous membranes.	Avoid contact with skin, eyes, and clothing. *
Phenolphthalein	Harmful by inhalation, in contact with skin and swallowed.	Avoid contact with skin and eyes. *

Table 4: Safety precautions and hazards related to chemical's

Materials	**Hazard**	**Precaution**
Burette	Breaking risk	Store the burette vertically in a dry and dust free environment, handle it with care.
Graduated cylinder	Breaking risk	Be sure that your workspace is clean and organized.
Beaker	Breaking risk	Should be heated on asbestos net to make sure that it heats evenly.
Distillation unit	Breaking and burning risk	Use proper personal protective equipment.
Heater	Burning risk	Keep it away from flammable materials.

Table 5: Safety precautions and hazards related to materials

Environmental concern:

The background research that is mentioned in the introduction part ("Rapid and Direct Iodine Value and Saponification Number Determination of Fats and Oils by Attenuated Total Reflectance/Fourier Transform Infrared Spectroscopy", "Saponification Process and Soap Chemistry") indicates that soap production has no adverse environmental effects, the soaps that are produced during the experiment do not contain any kinds of environmentally concerning materials (HCl, KOH, St. John's wort oil, bay seed oil, olive oil, cottonseed oil, magnesium oil, coconut oil, lanolin); hence, there are no environmental concerns associated with this practice. After the reaction, waste products do not impact the environment, provided proper chemical disposal protocols are adhered to.

Ethical concern:

The experiment did not involve human beings; hence, there were no significant ethical problems. Glassware was stored away from corners to prevent it from falling off tables and causing injury to nearby individuals. Following the utilization of the hot plate, a label indicating hot was affixed to the automatic hot plate to prevent subsequent users from sustaining burns.

Hypothesis:

The saponification values of soaps will vary significantly on the oil types used because of the differences in fatty acid chain lengths and structures. Oils which are composed of shorter chained fatty acids will exhibit higher saponification value (bay seed oil, coconut derived coconut oil), because shorter chain triglycerides have lower molecular weight which leads to a higher concentration of reactive ester sites per gram compared to others and this situation will lead to more requirement of KOH to saponify which leads to higher saponification value. Longer chained fatty acids (olive oil, lanolin, St. John's Wort oil) will have lower saponification values, because they contain higher molecular weights which leads to lower concentration of reactive ester sites per gram which requires less KOH resulting lower saponification value. Magnesium oil won't saponify at all because it is not an aqueous salt solution. My expectation on ranking of saponification values of these fats is: Coconut oil, bay seed oil, cottonseed oil, olive oil, St. John's Wort oil, lanolin, and magnesium oil respectively.

Procedure:

Before The Experiment

1. For preparing 0.500 mol dm^{-3} HCl solution:
   - Measure 500 cm^3 distilled water by graduated cylinder into a 1.00 dm^3 volumetric flask.
   - Carefully measure 41.5 cm^3 concentrated 37% by mass HCl by using a pipette.
   - Slowly add HCl into the water carefully while swirling it.
   - Allow the solutions to cool until they reach room temperature.
   - When they reach room temperature, add more distilled water by a volumetric flask up to the 1.00 dm^3 mark on the volumetric flask used.
   - Rinse and swirl the solution several times to make sure the solution is homogeneous.
2. For preparing 500 cm^3 solution 4% ethanolic KOH by mass:
   - By using spatula take solid KOH pellets and weigh 15.8 g of them by using the digital balance.
   - Measure 400 cm^3 ethanol by using a graduated cylinder and pour it in a 500 cm^3 beaker.
   - Carefully add the KOH pellets into the ethanol poured while stirring.
   - Allow the solution cool until it reaches room temperature.
   - Add ethanol until the 500 cm^3 mark on the volumetric flask and shake the flask.

During The Experiment

- **For Saponification**

1. By using a digital balance measure 5.00 g of each oil in a 250 cm^3 beaker.
2. Let the beaker and oil heat to 78°C by using the heating plate (all samples are sealed using parafilm). The temperature of the oils is measured by using a thermometer. The temperature of the oils is measured in every 10 seconds.
3. While oils are heated, the lye solution prepared beforehand the experiment containing ethanolic KOH should be taken.
4. Add the lye solution into heated oil while the automatic hot plate is still settled at 78°C and constantly stir by using the glass rod until it is forming a soap.
5. Pour the mixture formed into a mold and put into freezer for 24 hours to solidify them.
6. Repeat steps 1-5 must for all oil types.

- **For Titration**

1. By using digital balance measure 5.00 g of each oil and add 50 cm^3 4% ethanolic KOH by using graduated cylinder.
2. For the preparation of blank solution take 50 cm^3 4% ethanolic KOH by using graduated cylinder.
3. Let the beaker and oil heat for 30 minutes to 78°C by using the heating plate, all oil samples and blank sample are sealed by using parafilm.
4. Wait for 30 minutes for the solution to cool down.
5. For titration to start, put 3 drops of phenolphthalein by pipette into each sample and blank solution.
6. After putting the phenolphthalein, shake the solution to mix it.
7. Take 0.500 mol dm^{-3} of HCl solution into a burette by using a volumetric flask.

8. When the pink colour disappears read the volume.
9. Repeat steps 1-8 for 5 trials for each oil and blank solution.

- **For Testing Foaming**

1. For the foaming experiment, take the soaps from the freezer mentioned in “For Making Soap” section.
2. Divide and put 1.00 g of each soap sample into plastic burette that is containing 10 cm^3 of tap water.
3. Shake all samples for 10 seconds.
4. After shaking the samples for 10 seconds, measure the foaming height of each soap sample by using a ruler.

Results:

Qualitative Data:

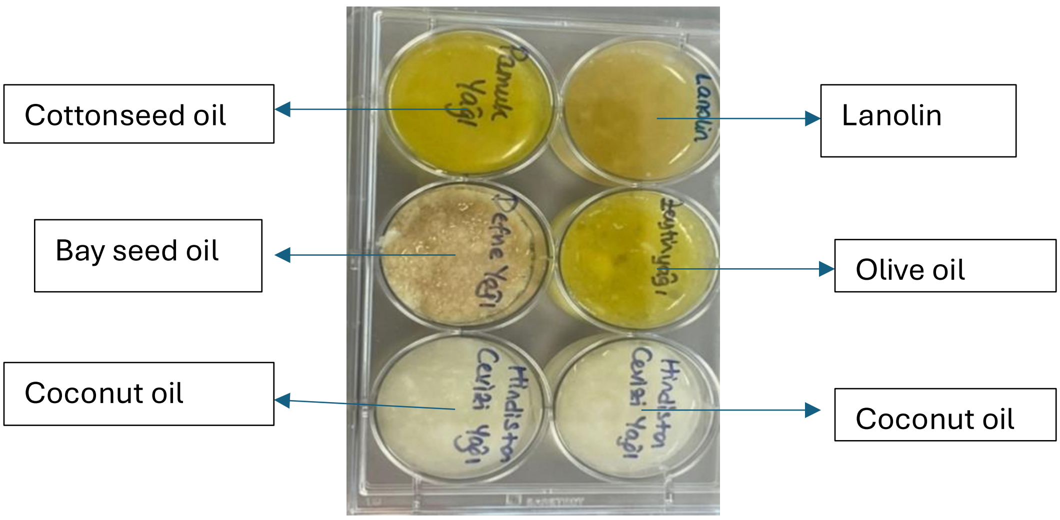


Figure 2: Shows the photograph of soaps made from different oil types (Cottonseed oil, lanolin, bay seed oil, olive oil, coconut oil) containing potassium hydroxide.

- Soap that is made from olive oil resulted to be the hardest and most favourable soap.
- Olive oil formed a pale yellow to greenish colour which is caused of chlorophyl inside the olive. Coconut oil produces a white coloured soap which is because of the low

pigment content in it. The bay seed oil produces a brownish coloured soap which is caused because of the chlorophyl and aromatics inside of it. Lanolin produces a yellowish soap because of the natural wax content in it. Cottonseed oil produces a yellowish soap because of the natural pigments in it.

- Lanolin oil produced a soft soap as well as olive oil. Coconut oil produced a hard soap as well as bay seed oil.

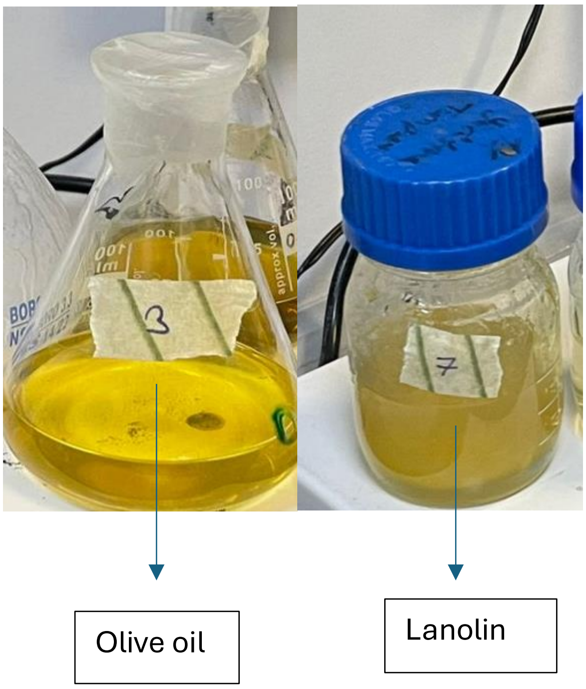
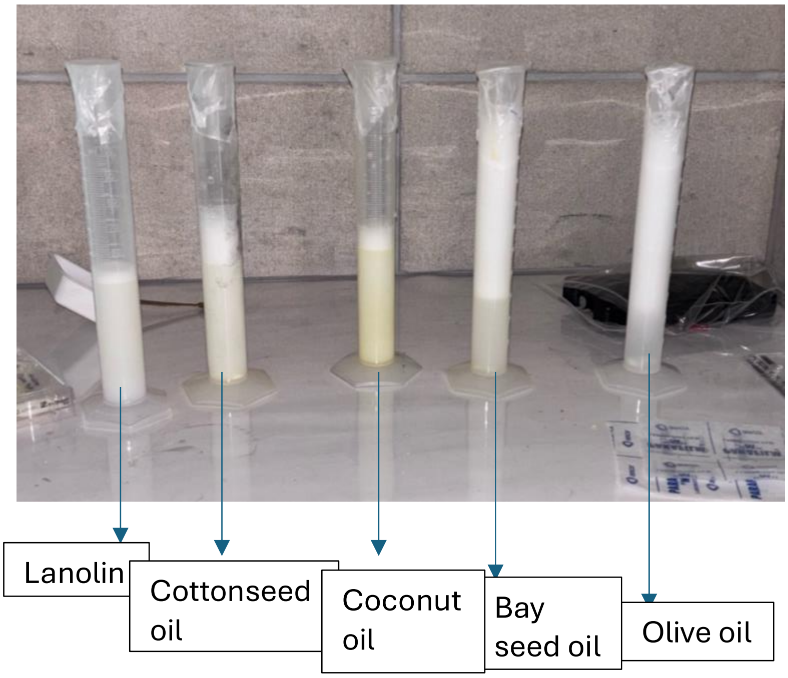


Figure 3: Shows the photograph of soaps made from lanolin and olive oil. This photograph shows that they formed a liquid-like structure which indicates that they are softer compared to others.

- After forming the lye solutions soaps are foamed to measure which soap is the most usable one and to measure which one cleans the best.



After foaming the soaps, the one that foamed the most is olive oil which can be estimated that it is the most usable and the one with highest cleaning rate.
The one that foamed least is lanolin, which can be estimated that it is the least usable one and have the least cleansing rate.

Figure 4: Shows the soaps that are foamed and how much they have foamed.

<u>Quantitative Data (Raw Data):</u>

RAW DATA: Volume of HCl, blank solution and mass of oil used.

St. Jhon's Wort oil	**Volume of HCl (V_S) (cm^3) $\pm$ 0.1**	**Volume of blank (V_B) (cm^3) $\pm$ 0.1**	**Mass of oil (W_S) (g) $\pm$ 0.01**
Trial 1	10.1	22.9	5.02
Trial 2	9.2	22.9	5.03
Trial 3	8.3	22.9	5.05
Trial 4	8.8	22.9	5.01
Trial 5	9.7	22.9	5.08

Table 6: Raw data table for St. Jhon's Wort oil

Bay seed oil	**V_S (cm^3) ± 0.1**	**V_B (cm^3) ± 0.1**	**W_S (g) ± 0.01**
Trial 1	7.2	22.9	5.02
Trial 2	6.3	22.9	5.08
Trial 3	4.1	22.9	5.09
Trial 4	4.3	22.9	5.03
Trial 5	5.8	22.9	5.04

Table 7: Raw data table for bay seed oil

Cottonseed oil	**V_S (cm^3) ± 0.1**	**V_B (cm^3) ± 0.1**	**W_S (g) ± 0.01**
Trial 1	8.3	22.9	5.05
Trial 2	7.5	22.9	5.05
Trial 3	7.4	22.9	5.06
Trial 4	7.7	22.9	5.07
Trial 5	7.9	22.9	5.09

Table 8: Raw data table for cottonseed oil

Magnesium oil	**V_S (cm^3) ± 0.1**	**V_B (cm^3) ± 0.1**	**W_S (g) ± 0.01**
Trial 1	14.1	22.9	6.27
Trial 2	14.2	22.9	6.23
Trial 3	13.5	22.9	6.29
Trial 4	14.6	22.9	6.22
Trial 5	14.3	22.9	6.22

Table 9: Raw data table for magnesium oil

Olive oil	**V_S (cm^3) ± 0.1**	**V_B (cm^3) ± 0.1**	**W_S (g) ± 0.01**
Trial 1	5.1	22.9	5.09
Trial 2	5.4	22.9	5.07
Trial 3	4.5	22.9	5.08
Trial 4	4.3	22.9	5.09
Trial 5	4.8	22.9	5.03

Table 10: Raw data table for olive oil

Coconut oil	**V_S (cm^3) ± 0.1**	**V_B (cm^3) ± 0.1**	**W_S (g) ± 0.01**
Trial 1	12.3	22.9	5.04
Trial 2	12.5	22.9	5.05
Trial 3	12.2	22.9	5.09
Trial 4	13.2	22.9	5.06
Trial 5	12.7	22.9	5.08

Table 11: Raw data table for coconut oil

Lanolin	**V_S (cm^3) ± 0.1**	**V_B (cm^3) ± 0.1**	**W_S (g) ± 0.01**
Trial 1	16.1	22.9	6.69
Trial 2	15.8	22.9	6.68
Trial 3	14.4	22.9	6.63
Trial 4	14.7	22.9	6.64
Trial 5	15.9	22.9	6.62

Table 12: Raw data table for lanolin

Soaping Height: Height of foamed soaps measured by using a ruler

Soaping Height (cm)	Lanolin	Cottonseed oil	Coconut oil	Olive oil	Bay seed oil
Trial 1	0.7 ± 0.5	2.1 ± 0.5	2.8 ± 0.5	11.4 ± 0.5	6.9 ± 0.5
Trial 2	0.9 ± 0.5	2.2 ± 0.5	2.7 ± 0.5	11.2 ± 0.5	6.7 ± 0.5

Table 13: Soaping height of lanolin, cottonseed oil, coconut oil, olive oil and bay seed oil

<u>Calculation:</u>

Saponification value and absolute uncertainty:

Sample Calculation	Formula	Example
Saponification Value (mg KOH/g)	$\frac{(V_B - V_S) \times M \times 56.10}{W_s}$ V_B: Volume of blank solution (cm^3) V_S: Volume of solution in titration (cm^3) W_S: Weight of oil sample M: mol dm^{-3} of HCl solution	Trial 2: Bay seed oil $\frac{28.05\ (22.9 - 6.3)}{5.08}$ = 91.7 mg KOH/1 gram oil
Absolute uncertainty	1. Adding up the uncertainties of V_B and V_S 2. Determine the percentage uncertainty of the numerator in the saponification value equation. 3. Determine the percentage uncertainty of the denominator in the saponification value equation. 4. Add up the percentage uncertainties. 5. To determine absolute uncertainty, divide the number by 100 and multiply by the saponification value.	1. 0.1 + 0.1 = 0.2 2. $\frac{0.2}{22.9-6.3} \times 100 = 1.2\%$ 3. $\frac{0.01}{5.08} \times 100 = 0.20\%$ 4. $1.2\% + 0.20\% \approx 1.4\%$ 5. $\frac{1.4}{100} \times 91.7 \approx 1.3$ Uncertainty = ± 1.3 Saponification value of bay seed oil for trial 2: 91.7 mg KOH/g ± 1.3

Table 14: Calculation of saponification value and absolute uncertainty with one example calculation for bay seed oil trial 2

The purpose of titration was to determine values of V_B and V_S. The initial volumes of all trails are considered as 0.00, and the initial reading was subtracted from the final volume to determine the titrated values.

Processed data: Comparison of theoretical and experimental saponification values.

St. Jhon's Wort oil	**Theoretical value**	**Saponification value (mg KOH/g)**
Trial 1	180-196	70.7 ± 1.2
Trial 2	180-196	76.4 ± 1.3
Trial 3	180-196	81.1 ± 1.3
Trial 4	180-196	78.9 ± 1.3
Trial 5	180-196	72.9 ± 1.3

Table 15: Processed data table for St. Jhon's Wort oil

Bay seed oil	**Theoretical value**	**Saponification value (mg KOH/g)**
Trial 1	245-260	87.7 ± 1.3
Trial 2	245-260	91.7 ± 1.3
Trial 3	245-260	104 ± 1.3
Trial 4	245-260	104 ± 1.3
Trial 5	245-260	95.2 ± 1.3

Table 16: Processed data table for bay seed oil

Cottonseed oil	**Theoretical value**	**Saponification value (mg KOH/g)**
Trial 1	189-207	81.1 ± 1.3
Trial 2	189-207	85.5 ± 1.3
Trial 3	189-207	85.9 ± 1.3
Trial 4	189-207	84.1 ± 1.3
Trial 5	189-207	82.7 ± 1.3

Table 17: Processed data table for cottonseed oil

Magnesium oil	**Theoretical value**	**Saponification value (mg KOH/g)**
Trial 1	0	39.4 ± 0.97
Trial 2	0	39.2 ± 0.98
Trial 3	0	41.9 ± 0.98
Trial 4	0	37.4 ± 0.98
Trial 5	0	38.8 ± 0.98

Table 18: Processed data table for magnesium oil

Olive oil	**Theoretical value**	**Saponification value (mg KOH/g)**
Trial 1	184-196	98.1 ± 1.3
Trial 2	184-196	96.8 ± 1.3
Trial 3	184-196	102 ± 1.3
Trial 4	184-196	103 ± 1.3
Trial 5	184-196	101 ± 1.3

Table 19: Processed data table for olive oil

Coconut oil	Theoretical value	Saponification value (mg KOH/g)
Trial 1	250-264	59.0 ± 1.2
Trial 2	250-264	57.8 ± 1.2
Trial 3	250-264	59.0 ± 1.2
Trial 4	250-264	53.8 ± 1.2
Trial 5	250-264	56.3 ± 1.2

Table 20: Processed data table for coconut oil

Lanolin	Theoretical value	Saponification value (mg KOH/g)
Trial 1	90-105	28.5 ± 0.90
Trial 2	90-105	29.8 ± 0.90
Trial 3	90-105	36.0 ± 0.92
Trial 4	90-105	34.6 ± 0.91
Trial 5	90-105	29.7 ± 0.91

Table 21: Processed data table for lanolin

Calculations Related to Samples:

1. **Standard Deviation:**

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i-\mu)^2}{\eta-1}}$$

σ: Standard deviation

Σ: Sum of variables

μ: Population mean

η: Number of data points

2. **Standard Error:**

$$SE = \frac{\sigma}{\sqrt{\eta}}$$

SE: Standard error

σ: Standard deviation

η: Number of trials done

3. **Mean Uncertainty:**

$$\Delta\bar{\boldsymbol{x}} = \frac{(\boldsymbol{maximum\ value - minimum\ value})}{\boldsymbol{2}}$$

$\Delta\bar{x}$: Mean uncertainty

Maximum value: Maximum value among the sample trials

Minimum value: Minimum value among the sample trials

4. **Percentage Error:**

$$Percantage\ Error = \left|\frac{Experimental\ Value - Theoretical\ Value}{Theoretical\ Value}\right| \times 100$$

Example Calculations:

All these example calculations will be conducted for bay seed oil saponification value.

$$\sigma = \sqrt{\frac{(96.5-87.7)^2+(96.5-91.7)^2+(104-96.5)^2+(104-96.5)^2+(96.5-95.2)^2}{4}} = 7.33$$

$$SE = \frac{7.33}{\sqrt{5}} = 3.28$$

$$\Delta\bar{x} = \frac{104 - 87.7}{2} = 8.15$$

$$Percantage\ Error = \left|\frac{96.5 - 253}{253}\right| \times 100 = 61.9$$

Average values	V_S (cm^3) ± 0.1	V_B (cm^3) ± 0.1	W_S (g) ± 0.01	Saponification value (mg KOH/g)
St. Jhon's Wort oil	9.22	22.9	5.04	76.0
Bay seed oil	5.54	22.9	5.05	96.5
Olive oil	4.82	22.9	5.07	100
Cottonseed oil	7.76	22.9	5.06	83.9
Magnesium oil	14.1	22.9	6.25	39.3
Coconut oil	12.6	22.9	5.06	57.2
Lanolin	15.4	22.9	6.65	31.7

Table 22: Shows the average saponification values of each oil type

Standard deviation	V_S (cm^3)	V_B (cm^3)	W_S (g)	Saponification value (mg KOH/g)
St. Jhon's Wort oil	0.712	0	0.03	4.25
Bay seed oil	1.32	0	0.03	7.33
Olive oil	0.444	0	0.02	2.63
Cottonseed oil	0.358	0	0.02	1.99
Magnesium oil	0.404	0	0.03	1.63
Coconut oil	0.354	0	0.02	2.19
Lanolin	0.772	0	0.03	3.34

Table 23: Shows the standard deviation of each oil type

Standard error	V_S (cm^3)	V_B (cm^3)	W_S (g)	Saponification value (mg KOH/g)
St. Jhon's Wort oil	0.318	0	0.01	1.90
Bay seed oil	0.590	0	0.01	3.28
Olive oil	0.198	0	0.01	1.18
Cottonseed oil	0.160	0	0.01	0.89
Magnesium oil	0.181	0	0.01	0.73
Coconut oil	0.158	0	0.01	0.98
Lanolin	0.345	0	0.01	1.49

Table 24: Shows the standard error of each oil type

Oil types	Mean uncertainty of Saponification value (mg KOH/g)
St. Jhon's Wort oil	5.20
Bay seed oil	8.15
Olive oil	3.10
Cottonseed oil	2.40
Magnesium oil	2.25
Coconut oil	2.60
Lanolin	3.75

Table 25: Shows the mean uncertainty of each oil type

Percentage error	Average theoretical value	Average experimental Value	Percentage error
St. John's Wort oil	188	76.0	59.6
Bay seed oil	253	96.5	61.9
Cottonseed oil	198	83.9	57.6
Magnesium oil	0	39.3	100
Olive oil	190	100	47.4
Coconut oil	257	57.2	77.7
Lanolin	97.5	31.7	67.5

Table 26: Shows the percentage error of each oil type

Foaming Process	Olive oil	Coconut oil	Cottonseed oil	Bay seed oil	Lanolin
Mean value	11.3	2.75	2.15	6.8	0.8
Standard deviation	0.14	0.07	0.07	0.14	0.14
Standard error	0.10	0.05	0.05	0.10	0.10

Table 27: Shows the mean value, standard deviation and standard error of foaming heights of each oil

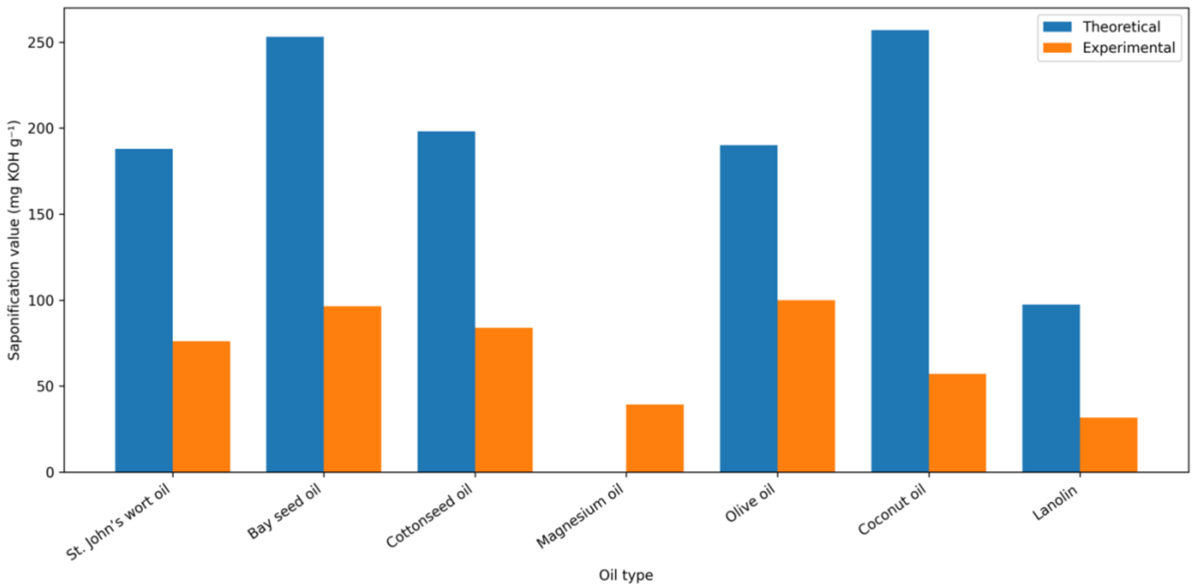


Figure 5: Bar graph for comparing experimental and theoretical values of each oil type

Conclusion:

According to the experiments that are done it has been found that olive oil has the highest mean saponification value (100 mg KOH/g), and lanolin has the lowest mean saponification value (31.7 KOH/g). The results of the experiments done are not same with the hypothesis given, this situation indicates that the results of the experiment may not always be totally consistent. The saponification values rely on the molecular weight and the percentage concentration of fatty acid components. The experimental saponification value of each oil is distinct, as it produces varying levels of saponification.

The reason of this situation may be the usage of not totally pure oils in the experiment, this situation can lead to results that are not similar with the hypothesis stated and theoretical values given. Another reason of this situation may be, related to dispersion and melting issues which leads to incomplete reaction. To illustrate, coconut oil is semi-solid in room temperature, if it is not totally melted because of its physical state during the heating process it could lead to leaving some triglycerides unreacted. This situation may lead to measuring the saponification value lower than its theoretical value. Bay seed oil has a waxy structure, if it has more viscous structure and wax esters which raise sample mass but do not consume KOH. This situation may lead to finding lower experimental saponification value.

Also, magnesium oil is not a triglyceride oil so saponification value is not meaningfully comparable, this leads to saponification method becoming invalid because KOH is consumed by the side reactions that occurs during the experiment (Gröber et al.). Hence, the experimental mean saponification value of 39.3 mg KOH/g of magnesium oil is best interpreted with apparent base consumption rather than true ester hydrolysis, this situation demonstrates why a non zero saponification value was observed from magnesium oil while it was expected to be zero.

The experimental value that is found is because of the consumption of side reactions. Additionally, by the foaming experiment that is done it can abundantly be seen that olive oil which has the highest saponification value also has the highest foaming height. Delving into specifics, olive oil produced the highest mean foaming height of 11.3 cm compared to other oils tested, bay seed oil produced a height of 6.8 cm, coconut oil 2.75 cm, cottonseed oil 2.15 cm, and lanolin 0.8 cm. These foaming heights supports the claim of a relation between higher saponification value and higher foaming height. This situation proves that the olive oil produces the best soap among the other samples from a different aspect. On contrary, foaming height is not a direct measure for stating a soap better or worse. Hence, the conclusion is limited to foaming performance rather than the cleansing ability of the soaps produced.

The article of "Saponification Process and Soap Chemistry" was read and by the soaping experiment done the articles topic of measuring the cleansing rate of soaps are measured.

Because of the skin concerns of the experiment, the rate of cleansing of the soap could not be measured on the skin. So the foaming experiment done supports the article "Rapid and Direct Iodine Value and Saponification Number Determination of Fats and Oils by Attenuated Total Reflectance/Fourier Transform Infrared Spectroscopy". Even though, infrared spectroscopy is a faster alternative, for this investigation it requires calibration curves. This situation makes the usage far from possible because many oils share overlapping ester peaks such as stretching of double bonds between carbon and oxygen or vibrations of single bonds between carbon and oxygen. Also, additional components such as free fatty acids may lead to overlapping bands. These overlaps can make it difficult to identify peak areas for specific chemical features for different oils, which would lead to reducing reliability without conducting advanced calibration.

The article given discusses the quality of soaps, the foaming experiment shows the data that the soap with the highest saponification value (olive oil) has the highest foaming height, this situation implies that the saponification value is proportional with the quality of the soap. In the dataset collected from this experiment, saponification value and foaming height show the same overall trend with olive oil being highest and lanolin being the lowest for both aspects. This situation supports the research question by indicating the situation of high saponification value producing a better soap.

The standard deviations of saponification value of St. John's wort oil, bay seed oil, olive oil, cottonseed oil, magnesium oil, coconut oil, lanolin are 4.25, 7.33, 2.63, 1.99, 1.63, 2.19, 3.34 respectively, the given standard deviations are low, so this situation implies that the values obtained from different trials are similar and precise. Since the trials are repeated for 5 times, the standard errors occurred are relatively small, this situation depicts a good reliability within each oil type.

To sum all up the experiments that are done answers the research question given, the saponification values and the foaming heights of the oils used through the experiment shows which type of oil will result a better soap. The saponification values of the oils examined were not in the theoretical value range. As the percent error is greater than the percent uncertainty there are both systematic and random error. Nearly all oil types demonstrate negative deviation from the theoretical values that are found from literature search. This circumstance supports an overall systematic error such as incomplete saponification or impurities. On the other hand, the standard deviation being low suggests that there is not a significant random error throughout the experiment.

These errors could be the purities of the oils that are used through the experiment and can also be the systematic errors which are occurred because of the equipment that are used through the experiment. As it can be seen in the percentage error calculations, the percentage error of the oils are high which indicates there is mostly systematic error. These errors will be discussed deeply in the evaluation part of this research.

Evaluation:

Strengths of the experiment:

1. Each of the samples were conducted into 5 trials, by these trials the consistency of the results was measured by measuring the standard deviation and standard error.
2. The foaming heights of the soaps formed are measured, by doing this experiment the cleaning rate and the quality of the soaps are measured. This measurement helps with stating which oil produces the better soap.
3. Usage of the heating plate, the usage of the heating plate helps with maintaining consistent temperature for all samples for the whole time that the experiment was done. Usage of this equipment conserves the heat loss overtime.
4. Experiment was carried out with the exact variables to ensure the experiment was precise with reducing the occurrence of random errors by keeping the conditions constant across all trials.
5. The exact saponification values of each oil was measured to determine that each oil has an unique saponification value which helps with forming a soap.

Weaknesses of the experiment:

1. Using not totally pure oils, usage of these not totally pure oils resulted different saponification values from theoretical values collected from experiments that are done in the past. Some of the oil types may consist of some impurities so distillation can be done for purification.
2. The foaming experiment that has done may not totally show the cleaning feature of the soaps that are formed, to improve the calculation of cleaning feature some further calculations may be done. For example, the statement of a soap being the hardest is qualitative, to make an objective statement hardness test is required.

3. To make the soap a better cleaner NaOH could be used as the lye solution instead of KOH because usage of NaOH will form a harder and resistant soap (*Lanolin - an Overview | ScienceDirect Topics*). However, KOH is the preferred lye solution for standard saponification value method, hence it is used in this experiment instead of NaOH.
4. The saponification value exhibited an uncertainty of roughly ±5, signifying a considerable degree of uncertainty. Employing devices with enhanced precision can alleviate these uncertainties. A 50 cm^3 burette with an uncertainty of ±0.05 cm^3, a balance with an uncertainty of ±0.001 g, a 100 cm^3 measuring cylinder with an uncertainty of ±0.5 cm^3, and a 250 cm^3 beaker with an uncertainty of ±1 cm^3 are all viable choices.
5. Rather than KOH, NaOH could have been used for the lye solution, NaOH would form a better soap because usage of NaOH would help the soap to be harder and more durable, this situation will enhance the soap to be better. However, changing the lye solution from KOH to NaOH would lead to change in reaction conditions, hence it should be stated as a further investigation rather than a direct fix.
6. The low standard deviations suggests that there are some random errors, however these had such a low impact on the ranking. On contrary, the consistently occurred negative deviations from theoretical values indicate that the systematic errors occurred affect all oil types in the same negative direction. These systematic errors lead to shifting all experimental saponification values downward even though the repeatability is good.

Improvements:

1. More trials could be done, with other oils and find their saponification values and foamed.
2. The lye solutions could be prepared with NaOH.
3. The oils that are used could be purified by doing distillation. For example, by using fresh oils oxidation exposure would be minimized.
4. The uncertainties of saponification could be tried to decrease. Standardizing the usage of KOH would directly reduce the systematic errors.
5. The hardness of the soaps could be measured, the situation of a soap being hard also helps to state which soap is the most favourable one. A simple hardness method would help to find the most favourable soap.

Further Investigation

1. Experiments could have been done with different temperatures to check whether the saponification values change in different temperatures.
2. Also experiments could have been done with different oil types to check whether there will be different results occurred. Additionally, conducting infrared spectroscopy could be done by preparing calibration standards and addressing peak overlap limitations.
3. Changing the lye solution from KOH to NaOH would change the reaction conditions, in order to make comparison for which lye solution would conduct a more favourable soap.

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