Sustainability by reduced energy consumption: changing raw materials and manufacturing processes in water-in-oil emulsions

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Introduction

Attempts to reduce the energy consumption and carbon footprint of cosmetic products are made by changing synthetic for natural ingredients, or hot for cold manufacturing processes. However, there is a scarcity of data quantifying these reductions to allow formulators to make fact-based decisions in this important area.

The aim of this study was to compare **the energy consumption and carbon footprint** of physico-chemically comparable water-in-oil (W/O) emulsions made with standard (mainly synthetic) and COSMOS-approved natural ingredients, respectively, using different manufacturing processes (hot, hot-cold and cold process emulsification).

Materials and Methods

- Six W/O emulsions were tested (**Figure 1** and **Table 1**).
- Hot-cold process involved heating only the oil phase.
- '**Scale-down calculations**' were performed beforehand, to coordinate the laboratory and manufacturing conditions.
- 500 g batches were prepared at 6600 rpm for 2 minutes and 20 seconds using the L5M homogeniser (Silverson, UK).
- The formulations were aimed for a typical 500 kg manufacturing vessel.

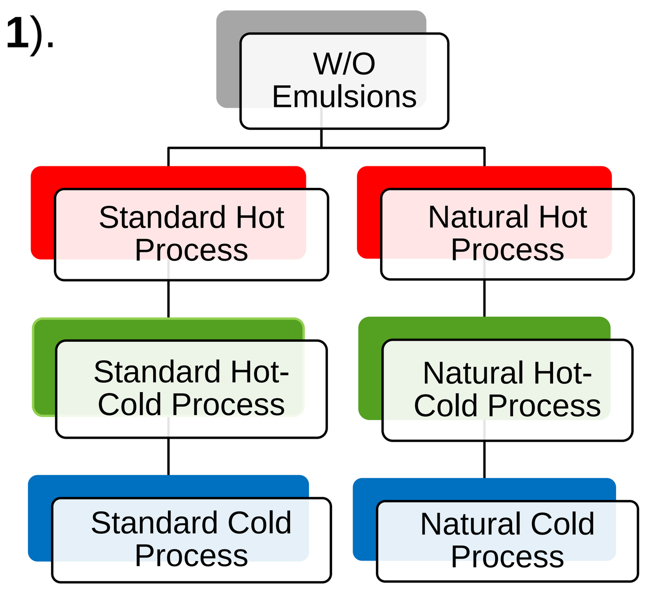

Figure 1. Emulsions prepared

Table 1. Standard and natural hot, hot-cold and cold process formulations

Phase	INCI name	Standard hot and hot-cold % (w/w)	Standard cold % (w/w)	Natural hot and hot-cold % (w/w)	Natural cold % (w/w)
A	Aqua	73.00	76.00	73.00	73.00
	Sodium Chloride	1.00	1.00	1.00	1.00
B	Paraffinum Liquidum	20.30	17.80	-	-
	Helianthus annus (Sunflower) Seed Oil	-	-	20.50	20.50
	Microcrystalline Wax (and) Paraffin Wax	1.50	-	-	-
	Cera alba	-	-	0.30	-
	Hydrogenated Castor Oil (and) Castor Oil	1.00	-	0.20	-
	Cetyl PEG/PPG-10/1 Dimethicone	2.50	2.50	-	-
	Polyglyceryl-4 Diisostearate/ Polyhydroxystearate/Sebacate (and) Caprylic/Capric Triglyceride (and) Poly-glyceryl-3 Oleate (and) Diisostearoyl Polyglyceryl-3 Dimer Dilinoleate	-	-	4.00	4.00
C	Zinc Stearate	-	2.00	-	0.50
D	Phenoxyethanol (and) Ethylhexylglycerin	0.70	0.70	-	-
	Dehydroacetic Acid (and) Benzyl Alcohol	-	-	0.70	0.70
	Tocopherol	-	-	0.30	0.30

- Emulsion stability: centrifuge test and 6 weeks at room temperature and 40 °C.
- Emulsions were characterised by continuous flow and oscillatory rheology (Haake Mars iQ Air, ThermoFisher Scientific, UK) and texture analyser immersion/de-immersion test (TA.XT Plus, Stable Micro Systems, UK).
- Thermal energy consumption, as well as the **carbon footprint using cradle-to-gate life cycle analysis** (LCA) (Benchmark, UK), of each emulsion were calculated.
- Melting temperatures of the oil phase mixtures were determined using differential scanning calorimetry (DSC) (DSC 3 STAR System, Mettler Toledo, Switzerland).

Results and Discussion

Figure 2 showcases viscosity at varying shear rates, as well as rigidity (complex modulus G*) and elasticity (phase angle δ).

Hot-cold process emulsions were slightly more viscous, rigid and elastic than the hot process emulsions despite their identical formulations, possibly due to the hot-cold manufacturing process cooling the oil phase down more quickly and leading to changes in the wax crystallisation behaviour [1]. This should be researched further for possible additional savings.

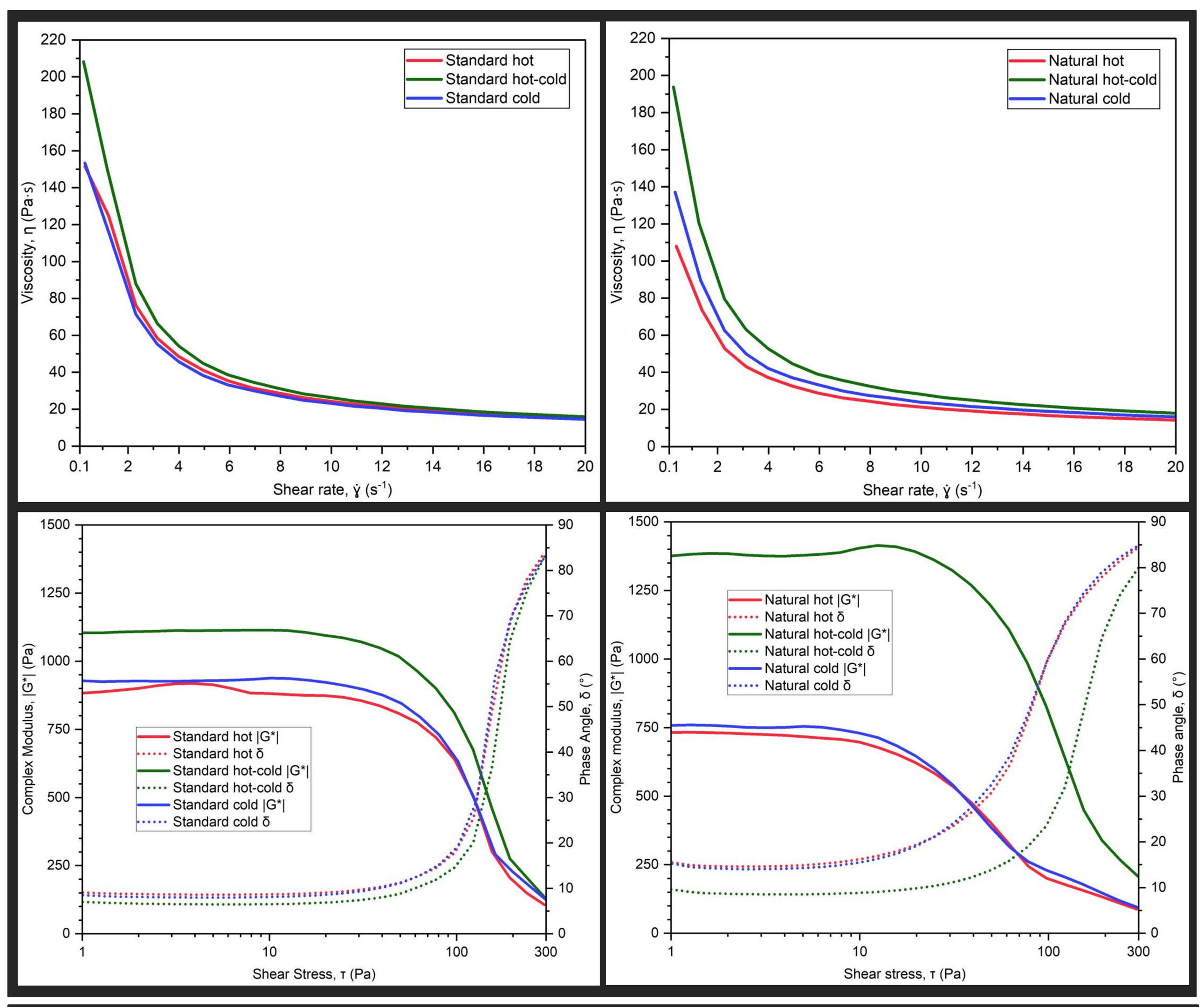

Figure 2. Shear rate sweep curves (above) and oscillatory stress sweep curves (below) for standard and natural hot, hot-cold and cold process emulsions

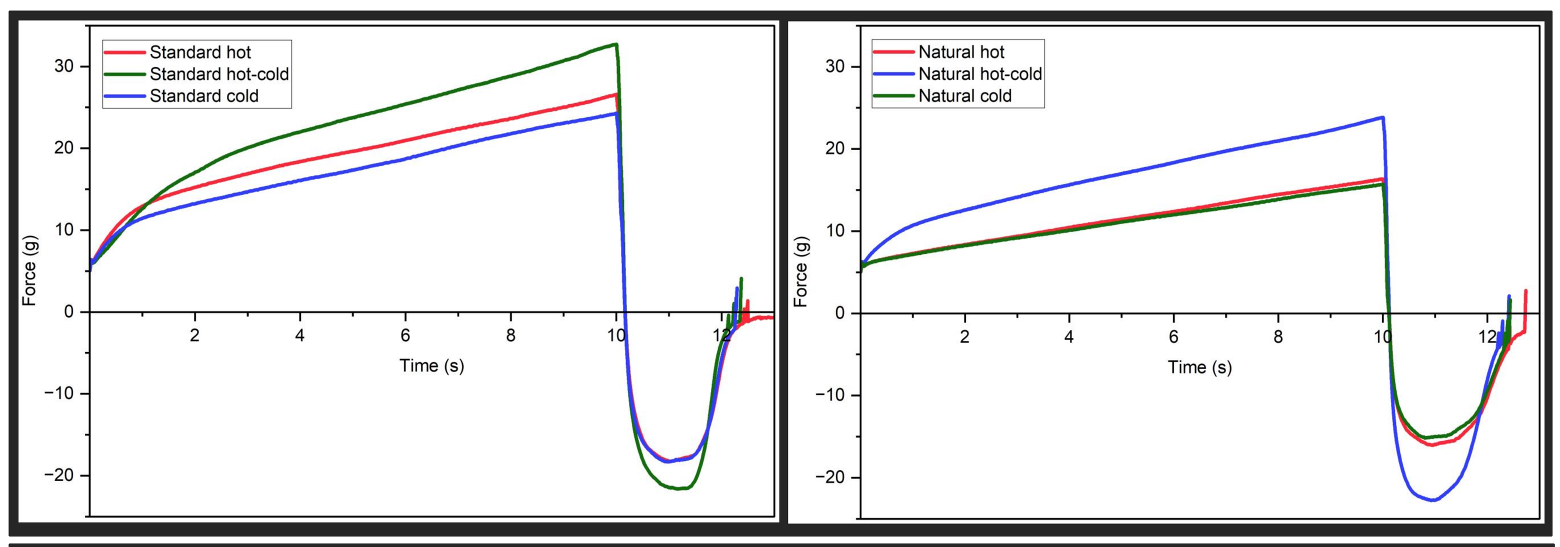

Figure 3. Immersion/de-immersion curves for standard and natural hot, hot-cold and cold process emulsions

Based on TA results (**Figure 3**) hot-cold process, as well as standard emulsions may be perceived as slightly less spreadable than their hot/cold and natural counterparts, respectively [2]. Further fine-tuning would produce sensorily almost identical formulations, as well as take care of some stability issues. However, **for the purpose of this study, the six emulsions presented a suitable model** for the comparison of their thermal energy consumption and total carbon footprint during manufacture.

Thermal energy makes up to 95 % of the total manufacturing energy [3]. While 100 % of the thermal energy was saved when moving from a hot to a cold manufacturing process, our calculations (**Table 2**) show that **approximately 85 % of thermal energy was already saved** when moving from a hot to a hot-cold manufacturing process due to the high heat capacity of water.

Table 2. Thermal energy consumption to manufacture 500 kg emulsions

Formulation	Thermal Energy (MJ) to Manufacture 500 kg: Water Phase	Oil Phase	Total	Thermal Energy Saving (%)
Standard Hot	191.96	30.66	222.62	-
Standard Hot-Cold	-	30.66	30.66	86.23
Standard Cold	-	-	-	100
Natural Hot	191.96	34.24	226.20	-
Natural Hot-Cold	-	34.24	34.24	84.86
Natural Cold	-	-	-	100

DSC revealed that oil phase mixtures had lower endset melting temperatures than constituent waxes (**Table 3**). Reducing from 82 °C to the new recommended manufacturing temperature of 63 °C for the natural hot/hot-cold process, **could save more than 30 % of the thermal energy.**

Table 3. Endset and recommended melting temperatures of standard and natural oil phases and corresponding energy saving

Oil Phase	Endset Temp. (°C)	Recommended Melting Temp. (°C)	Energy Saving (%)
Standard	81.9	82.0	-
Natural	63.0	63.0	30.65

The LCA results confirmed that the manufacturing process had a major impact on the carbon footprint of the final emulsion, with a **25 % and 29 % reduction from the hot process to the hot-cold and cold process, respectively** (**Table 4**).

Carbon footprint reductions were less than thermal energy reductions, highlighting that other energy inputs, such as indirect and mechanical, are also important contributors.

Table 4. Cradle-to-gate CO2e (carbon dioxide equivalent) figures for 500 kg emulsions

Formulation	Raw Material CO_2e (kg)	Manufacturing CO_2e (kg)	Packaging CO_2e (kg)	Total CO_2e (kg)
Standard Hot	0.15	204.38	29.58	234.11
Standard Hot-Cold	0.15	146.16	29.58	175.89
Standard Cold	0.14	136.85	29.58	166.57
Natural Hot	1.07	205.46	29.58	236.11
Natural Hot-Cold	1.07	147.24	29.58	177.89
Natural Cold	1.04	136.85	29.58	167.47

LCA also revealed that, contrary to expectations, natural ingredients used in this study had a slightly higher carbon footprint than standard ingredients. However, this fact had a low impact on the overall carbon footprint of the products, which was dominated by the manufacturing method.

Conclusion

- Rheologically and texturally similar W/O emulsions can be achieved at lower energy consumption and carbon footprint through use of **hot-cold and cold process** (with appropriate formulation adaptations).
- **The hot-cold manufacturing process saves approximately 85 % of thermal energy** and did not require the change in formulations.
- **Switching from synthetic to natural ingredients** could either increase or decrease the carbon footprint, but **the effect is almost negligible**.
- **Scale down calculations**, and the use of **DSC to confirm the melting temperature of the oil phase** should be used to save further energy.

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