Soap based thermal insulation: A sustainable alternative to petroleum

Read, L and Arayici, Y

Soap Based Thermal Insulation: A Sustainable Alternative to Petroleum Insulations

Lee Read, Yusuf Arayici

School of the Built Environment, University of Salford, The Crescent, Salford, M5 4WT.

School of the Built Environment, University of Salford, The Crescent, Salford, M5 4WT.

Email: l.read@edu.salford.ac.uk

Abstract:

The thermal insulation market is dominated by petroleum insulations. A gap has been identified for the manufacture of "green" insulations. These insulations must perform to the same levels of heat transfer resistance as their petroleum based counterparts.

Modern petroleum derived insulations can be carcinogenic, toxic to manufacture and release toxins as they degrade. The majority are not environmentally friendly. The aim of this research is to create an insulation that combats the above points and addresses the gap between sustainable and non-sustainable insulations.

This research will address the uncertainties in the alternative insulation validation process, achieved through experimental research. Soap will be manufactured from lye, animal fats and oils and aerated to produce soap insulation. These manufactured soap samples will be tested in both laboratory and real-world settings. Soap insulation could be a useful addition to low environmental impact insulations and create a foundation for further research to build off.

Keywords:

Petroleum Based Thermal Insulation, Soap Based Thermal Insulation, Sustainability, Lye, Oils,

Introduction

The research aim/objective is to manufacture a sustainable thermal insulation, derived predominately from waste products that can be used as an alternative to petroleum based insulations. The problem is whether aerated soap can perform to the same increased efficiency levels as its chemical based counterparts, whilst decreasing the environmental costs of fossil fuel retrieval, plastic manufacture and end of life waste disposal. Soap insulation, derived from soap in its most basic form, (fats, oils and wood ash residue) is natural (Grosso, 2002) and could be one possible advancement in a quest to encourage sustainable building. Combining fats and lye will create a hard, crude soap mixture that once

aerated and left to cool can be cut into slabs and surrounded in recycled plastic to create thermal insulation products. Trapped bubbles within the insulation will give the insulation its thermal properties (DeGunther, 2010). In order to satisfy the objective, 4 methods of research must be satisfied:

1. Refining the gathered evidence and identifying the limitations of the methods used.

2. Collecting, organising and interpreting the data to determine the best way forward, through experimental research.

3. A research strategy to ensure that the design of the study strategy is appropriate to achieve the research objective.

4. A manufacturing process of continual improvement through experiments and literature reviews of existing thermal insulations.

1.1: ***Background to Thermal Insulation***

There are four main types of foamed plastic wall, floor and roof insulation that are commonly used within the construction industry. Alongside these, multi-layered reflective foil and fibreglass insulations are also used. Green, sustainable insulations are becoming more popular, but occupy a very small niche in the market generally. The six main insulation types are as follows:

1. Extruded polystyrene (XPS)

2. Extruded polyethylene (XPE)

3. Expanded polystyrene (EPS).

4. Polyurethane (PUR) and polyisocyanurate (PIR)

5. Fibreglass

6. Multifoil

Sustainable thermal insulation products derived from paper, wool, hemp and cotton fibres have recently become available for use, although these “green” products occupy a somewhat limited niche in the marketplace.

1.2: *Potential Environmental Problems with Insulation manufacturing*

On an environmental level, the impact of petroleum based plastics and refined oil is threefold. 1. The retrieval of oil cannot be considered as sustainable. The limited supplies remaining and the damage caused to the environment by retrieval, is in direct opposition to the "green" energy alternatives.

2. The refining process of crude oil and the processes involved in plastic and foamed plastic insulation component manufacture, involve high greenhouse gas output emissions as a by-product and high energy consumption throughout the product's start to finish manufacturing ratios. The refining process relies on the combustion of fossil fuels for this heating, whilst the recovery units emit large amounts of methane and carbon dioxide, making the oil refining industry a significant source of emissions (Worrell & Galitsky, 2005).

3. End of life disposal of the insulation products can have a negative impact on the natural environment. Traditional insulations are difficult to dispose of in an ecologically friendly manner. In the UK, the majority of waste insulation finds its way to landfill sites where it can leach toxins into the soil as it degrades (Rogers, 2005).

2. Experimentation of Soap Production through Stages

Soap insulation must satisfy certain criteria in order for it to achieve mainstream acceptance. In order to satisfy the criteria, various obstacles must be overcome. Primarily, melted fats or oils must be turned into a solid. First, it would be useful to know the definition of oil and fats. Fats are the oily substance occurring in the adipose tissue of some animals and in the fruits, nuts and seeds of some plants. They are usually solid at room temperature (Joachim, 2001). Oils have the same chemical structure as fats, but are usually liquid at room temperature.

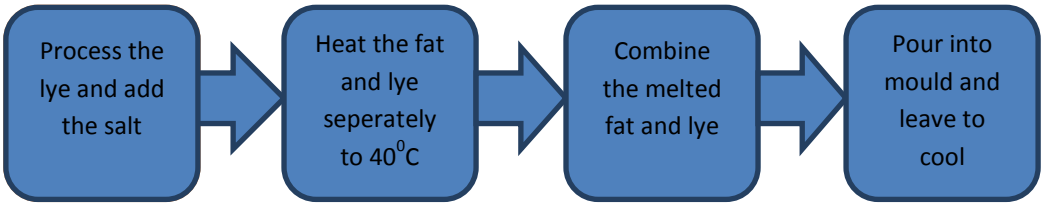


Fig.1: Soap Development Process. (Read, 2012)

2.1. *Stage 1: Lye Production*

Lye Description

Burnt wood residue (ash) left to leach in water for a number of days will change the water into a hydroxide alkaline solution known as lye (Tro, 2012). This caustic solution is a strong corrosive metallic base (Tro, 2012). Sodium hydroxide [NaOH] and potassium hydroxide [KOH]) can both be extracted from wood ash, although wood ash typically contains up to 10 times more potassium than sodium (Journey to forever, 2011). It should be explained that both sodium and potassium are soft white metals, in this case derived from common salt (sodium chloride) and potash (Clegg et al, 2002).

Manufacturing the Lye

It should be noted that the experimentation of soap production was done by the author. Soap insulation research is unique, as demonstrated by the awarding of a patent on the idea. As such there is little literature to reference. Potassium hydroxide was created by adapting the instructions given on the website "Journey to Forever" (2011). Oak branches were burnt because hardwoods leach more lye than softwoods. (Journey to Forever, 2011).The ashes were then collected. A barrel was sourced and a 100mm covering of gravel was placed inside the bottom. 150mm of hay was placed on top of this gravel. This was the filtration system. A small hole was drilled into the bottom of the barrel and a cork fitted to act as a plug. 10 litres of ash was placed into the barrel and 30 litres of rainwater poured over the ash and allowed to settle. The resulting mixture was allowed to sit for seven days, with occasional stirring. The water was then drained off, strained though a nylon sieve and then filtered into a jar.

2.2. *Stage 2: Initial Coarse Soap Output in the Soap Production Process*

A potential of hydrogen test was carried out on this lye liquid and the mixture was confirmed as alkaline registering a confirmation of 14 on the indicator testing strip. 125g of lye was then placed into containers for use in the manufacture of the soap test samples. Two soap samples were manufactured using the ashes derived potassium hydroxide and beef fat (125g of KOH and 250g of fat). One sample was blended and left to solidify. 40g of common salt was added to the other sample, then blended and left to solidify. The results were as follows:

- The potassium hydroxide soap without the added salt set to a semi solid state, somewhere between a liquid and a solid.

- The potassium hydroxide soap with added salt (In effect the KOH now converted to NaOH) set solid over a 10 minute period. The manufacturing process was repeated with each of the following fats: beef fat, pork fat, palm oil, used waste vegetable oil and used waste engine oil. All of the samples were mixed as per the following proportions: 250g of fat/oil and 125g of sodium hydroxide, and the "cold process" method was used for the manufacture. The soap setting time results are shown in Table 1.

2.2.1: ***Results for the Initial Soap Production (different fat types)***

Oil ingredient	Time achieve trace	Setting time (solid)
Beef fat	90 seconds	10 minutes
Pork fat	2 minutes	1 hour
Palm oil	5 minutes	1 hour
Waste vegetable oil	6 minutes	30 hours
Waste engine oil	12 minutes	60 hours*

Table 1: Soap setting times. (Read, 2012)

As can be seen from the "soap setting time" table, Beef, pork and palm oil have similar consistencies and create soap over a broadly similar time-frame. This is because the proportions of fats within the oil have a direct bearing on the length of time required for the soap to set hard. It should be noted that the waste engine oil used in the soap sample failed to set into a hard solid soap, but instead into a soft, flexible, "rubbery" material (Shown in Fig.2). It was decided that further research into soap insulation using waste engine oil as the base would be discontinued at this stage, with possible further research in the future. Soap samples manufactured from the other four oils set hard (see Fig. 3) on the following page.

Fig.2: This waste engine oil soap remained in a “blancmange” state. (Read, 2012)

Fig.3: A block of hard, solid, waste vegetable oil soap. (Read, 2012)

2.3. *Stage 3: Improving the Course Soap into the Lightweight Soap*

2.3.1: *Selection of the Cold Process Over the Hot Process for the Soap Manufacturing*

The cold process soap manufacturing method is the method used for the research experiments in this report. This method is chosen over the “hot process” because of the speed in which the soap reaches saponification (5 minutes as opposed to 3 hours). The cold process involves

adding measured amounts of lye to water and mixing it with heated oil, whilst both ingredients are stabilized at a temperature of 40^0 C. The mixture is blended until it thickens (achieves trace) and then poured into a mould to set (Palmer, 2007). The hot process requires the lye and oil mixture to be cooked (alternating heating and cooling) for three hours in a slow cooker, poured into moulds and left to harden (Grosso, 2003). This method boils off excess water from the mix and negates the need to mix the lye and oil at the precisely the same temperature (40^0C). In both processes the saponification setting action reduces the lye soap mixture from a highly alkaline substance to one that is pH neutral.

2.3.2: *Making the Soap Lightweight*

As stated previously, mixing oils and lye will create a hard soap mixture that once cooled can be cut into rigid boards and surrounded in plastic to create thermal insulation. The air bubbles within the soap should give the insulation its thermal properties. The arrangement of the molecules within these air pockets is such to utilize air as the insulator.

In order to make this product lightweight (and thermally efficient), it was necessary to aerate the mixtures. The mixing ratios listed previously were used in the manufacture of the following test samples and the weight and weight differential was recorded in fig.4. Various methods of aerating soap were tried. These included the addition of paper fibre balls, polythene balls, ice spheres, straw, expanded Expancel microspheres and sodium bicarbonate. The methods used to manufacture the test samples are shown on the following section.

2.4. *Stage 4: Improving the Lightweight Soap with Various Additives*

2.4.1: *Soap with no Additives (Control Soap for Benchmarking)*

A sample of soap was mixed using the following ingredients. 250g beef fat and 125g of lye. This was an identical ingredients mix as was used for the subsequent soap batches, but in this, no aerating additives were included. This soap with no additives was used as the control.

2.4.2: *Soap with Added Straw*

Another method of creating a lightweight aerated sample was the introduction of short fibres of straw into the mix. Straw is hollow and is a good insulator. It is a by-product of farming and is totally biodegradable. For the soap experiment, 15g of Straw cut into lengths of 10mm - 15mm were added to a soap sample mixture. The additive equated to 50% of the soap mould's cubic volume.

2.4.3: *Soap with Added Expancel*

Yet another method of aerating the soap was the introduction of *Expancel* microspheres. These microspheres are tiny copolymer and isobutane spherical particles that expand to many times their original size by the introduction of heat. However, for the heat process to work, the mixture that the spheres are introduced into must reach a temperature of 80^0C -250^0C (Expancel, 2011). However, soap temperature when mixing and setting peaks at around 50^0C. It is the heat that triggers the spheres' expansion. Already expanded microspheres can be introduced into a mixture though. This addition not only aerates the mixture, but also gives the finished structure compressibility and lightweight properties (depending on the amount introduced), ideal for insulation products. The one drawback of using Expancel is that the insulation product is no longer *entirely* natural, recycled or chemical free. For this soap mixture, as with the other test samples, the soap ingredients were of identical proportions. The water was heated to 100^oC in order to initiate a reaction from the Expancel powder. The Expancel was weighed at 0.5g (4 tablespoons) and added to the water and lye mixture. The normal process of blending to achieve trace, and the pouring of the liquid soap into the mould to cure was completed. The weight of the product was recorded one week later.

2.4.4: *Soap with Added Paper Spheres*

Small, hollow, dried waste paper based spheres can be introduced into the soap mixture in place of straw. These can be lightweight cellulose fibres and of the type normally used as stabilizing additives to stone mastic asphalts and hot rolled asphalts (highways), or the more paper based, as used in art and craft hobbies. The paper can be recycled from low quality products such as newspapers etc. The size of these particles is typically 10mm – 15mm.

An identical base mixture as listed previously was created, but this time with the addition of 37g of 15mm paper balls. This 37g equated to approximately one half of the soap mould cubic area by volume. This left a sufficient volume of soap to bind the mixture together for the product strength.

2.4.5: *Soap with PEHD Spheres*

An alternative to paper is to use small (10mm) hollow plastic balls made from waste PEHD. These are also extremely lightweight and should also give the insulation good thermal properties. This batch of soap was made in an identical way as the previous ball additive soap, only this time the paper balls were replaced with 25g of 10mm PEHD hollow spheres.

2.4.6: *Soap with Added Ice*

The rationale behind this idea was that ice particles would be another method of aerating the soap. Small ice spheres would be substituted for the straw, paper and "Expancel". The ice would be introduced into the mix and as the temperature of the soap increased, and thus solidified, the melted ice would leave air pockets throughout. This should give the product lightweight properties.

Once again, another batch of soap was mixed but this time 10mm ice cubes were added as an ingredient. The ice was added to a batch of trace soap liquid but the soap immediately solidified on contact (with the ice). A test liquid soap mixture was introduced to a container of cold water and this soap also solidified instantly. Further investigation of ice added to the soap was discontinued.

2.4.7: *Soap with Added Sodium Bicarbonate ($NaHCO_3$)*

Aerating with an alternative, more natural additive was tried next. A bicarbonate of soda (baking powder) and vinegar foaming agent was compiled, at a ratio of two teaspoons to four respectively. This mixture foamed violently immediately the vinegar and soda came into contact with each other. This froth was introduced into the soap at the soap's liquid stage, after trace had occurred so as not to let the bicarbonate mix interfere with the actual saponification process (where the fat and lye combined to form the soap). The mixture was blended together and left to cure.

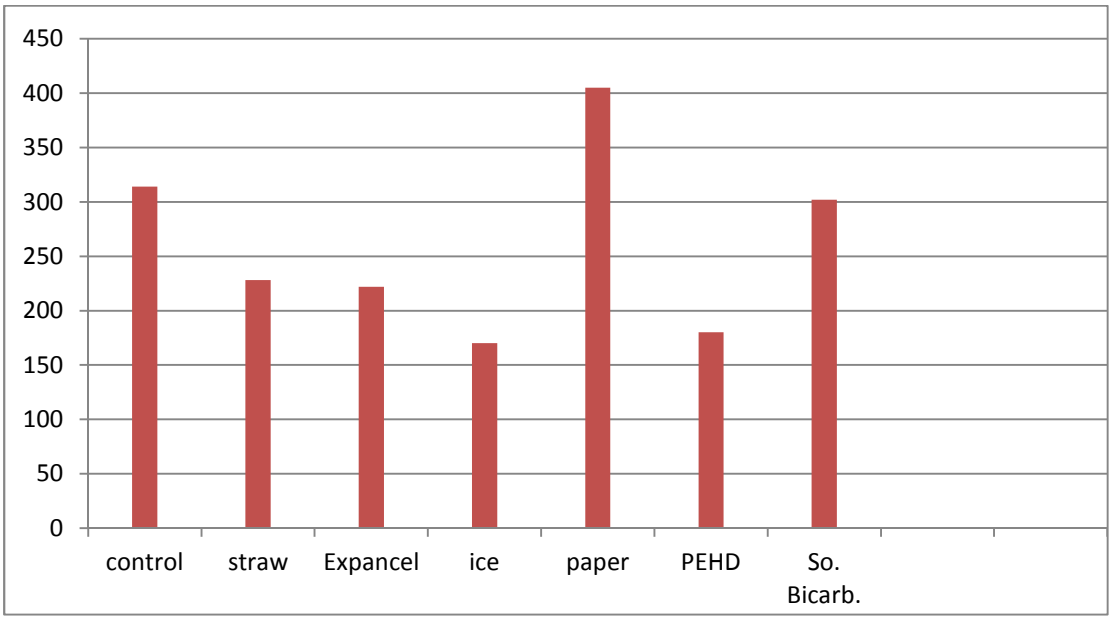
Observation revealed the soap to have separated into distinct layers. Soap occupied the bottom two thirds of the soap mould with ponding on the top third. The top third was a clear liquid with a salt glazed surface. A potential of hydrogen strip revealed the liquid to be an acid with a pH of 5, whilst the soap below was alkaline with a pH of 13. The liquid was drained off and the soap was left to solidify. However, the soap failed to set firm and remained in a gel state. It also remained in a highly alkaline state.

In effect the addition of the blowing agent had separated the soap into three distinct layers, alkaline at the bottom, acid in the middle and salt on the top surface. Research using this type of mixed foaming agent was discontinued, with the next batch mixed using just sodium bicarbonate alone, in its powdered form. When compared with the control (soap with no additives), the sodium bicarbonate soap was slightly lower in weight than the control. However, the soap did not set hard enough to be considered for use as an insulation material.

The soap structure had been considerably weakened by the addition of sodium bicarbonate and so this product was deemed unsuitable for purpose and further research into this particular product was halted.

2.5. Stage 5: *Comparative Analysis of Aeration Methods with the Control Soap*

Following manufacture the soap samples were dried and a moisture content reading was taken for each sample. When all of the samples had an identical reading of 35%, the samples were weighed. The results are recorded in the bar graph on the following page (Fig.4).



The vertical axis shows the weight in grams

Fig. 4: Soap weight graph shows how additives affect soap weight. (Read, 2012)

The table below (Table 2) shows the weight percentage difference between the control soap and the soaps with the aerating additives.

Paper balls*	29%	Heavier than the control
Plastic balls	43%	Lighter than the control
Ice balls*	46%	Lighter than the control
Straw	27%	Lighter than the control
Expancel	29%	Lighter than the control
Sodium bicarbonate*	4%	Lighter than the control

Table 2 Weight Difference Between soaps. (Read, 2012)

*Discontinued from further study.

Results showed that soap with added paper balls increased in weight. There is a possibility for this. The lightweight paper balls absorb and retain moisture from within the mixture, thus trapping the moisture inside of the sample, whilst the rest of the soap dries out.

The worst performers, soap with the paper balls, ice and baking powder were discontinued from this study with a view to possible investigation in the future. Out of the six samples tested, only three moved on to the next stage.

2.5.1: ***An Alternative Method of Aeration***

Another batch of soap was mixed and was aerated using a method that is employed sometimes when making aerated chocolate (Barrett, 2012). This method would be to introduce air into the mixture under pressure. This would take place in a hermetically sealed container, with the air being sucked out from this container, creating a vacuum inside. This removal of air should create bubbles within the soap before it solidifies. Some brands of bubble chocolate have air introduced into the bar in this way (Chocablog, 2010).

The soap mixture was poured into a compressed gas (nitrous oxide) whipped cream dispenser. The soap was then fired under pressure into a plastic box with a sealable lid (the lid had a previously cut 5mm hole through its surface). The box was placed into a PVC vacuum bag and the bag opening zipped closed. The vacuum hole in the bag was aligned to the hole in the box lid. A vacuum cleaner sucked the air out of both the bag and the container. The bag was placed into a fridge for 1 hour and then removed. The soap was weighed and the results were recorded (29% lighter than the control soap of equivalent cubic volume). The soap was then dissected to examine the bubble content (fig 5). Although the soap was aerated, the bubbles were small (approximately 1-3mm width generally). However, with the preliminary experimentation into aerating the soap successful, the way was clear to refine and expand on the results to improve its overall thermal efficiency capabilities.

Fig. 5: aerated soap created by the vacuum method. (Read, 2012)

2.6. *Stage 6*: *Increasing the Elasticity of Soap*

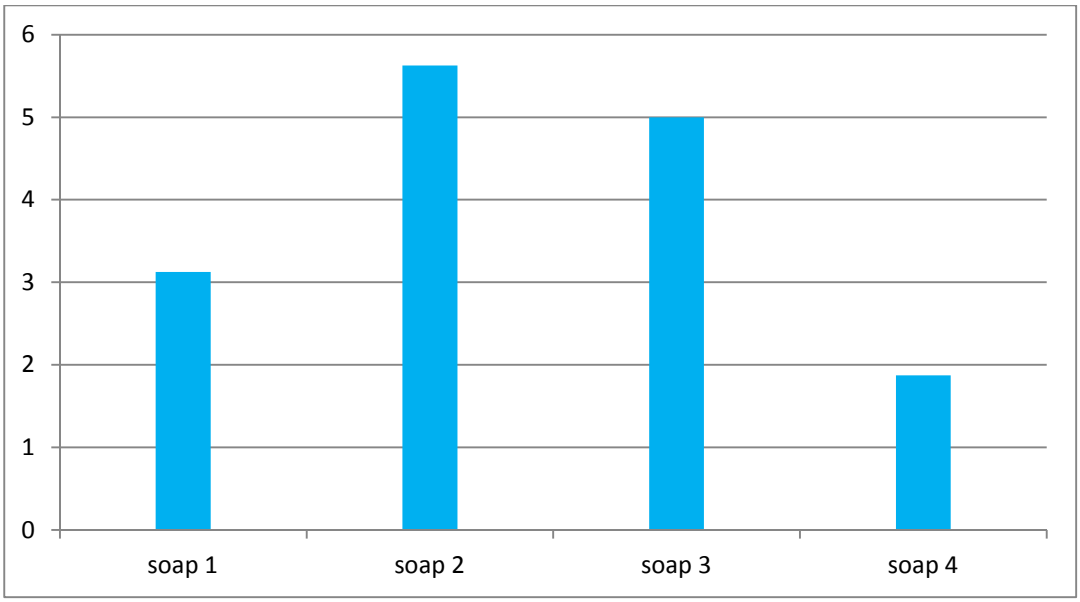
In order that the insulation can withstand on site knocks without breaking and retain its shape throughout its lifetime, the soap must be strengthened. In the test samples this was achieved by the addition of cotton thread fibres, added wool fibres and the addition of animal glue dispersed within the mixture at the soap's liquid stage before it hardens. Animal glue is natural and is derived as a by-product of the meat slaughtering industry (Gooch, 1997).

2.6.1: *Soap with Added Glue*

The object of manufacturing then testing the reinforced soap was to gauge the strengthening measures of the additives in the soap as a whole. (Tensile testing was also repeated, but on aerated soap this time. These results are recorded in fig.6, further into this chapter). One soap sample contained no strengthening measures, and this was used as the control. Different soaps will give different readings due to their ingredients and composition. Because of this, all four testing samples were made from the same batch of soap mixture. All four samples were sized at 100mm X 100mm surface area, 25mm thick. The tensile breaking points of each soap sample recorded in fig. 6.

2.6.2: *Soap with Added Wool and Cotton Fibres*

Wool and cotton fibres were added to the soap samples at the mixing stage. This addition was designed to improve the elasticity of the soap and improve its tensile strength. The strength testing results are also recorded in fig 6.



Side measurements are tensile strength measurements in psi. (lbs. per square inch)

Fig. 6: Failure of soap chart. (Read, 2012)

Soap 1: control (no additives)

Soap 2: Added wool fibres

Soap 3: Added cotton thread fibres

Soap 4: Added glue

The tensile strength of the soap samples were determined by using the following formula: The surface area (in inches squared) is subjected to applied loading (in lb's). The breaking point force was recorded. The applied load was divided by the soap surface area to determine the tensile strength of the soap.

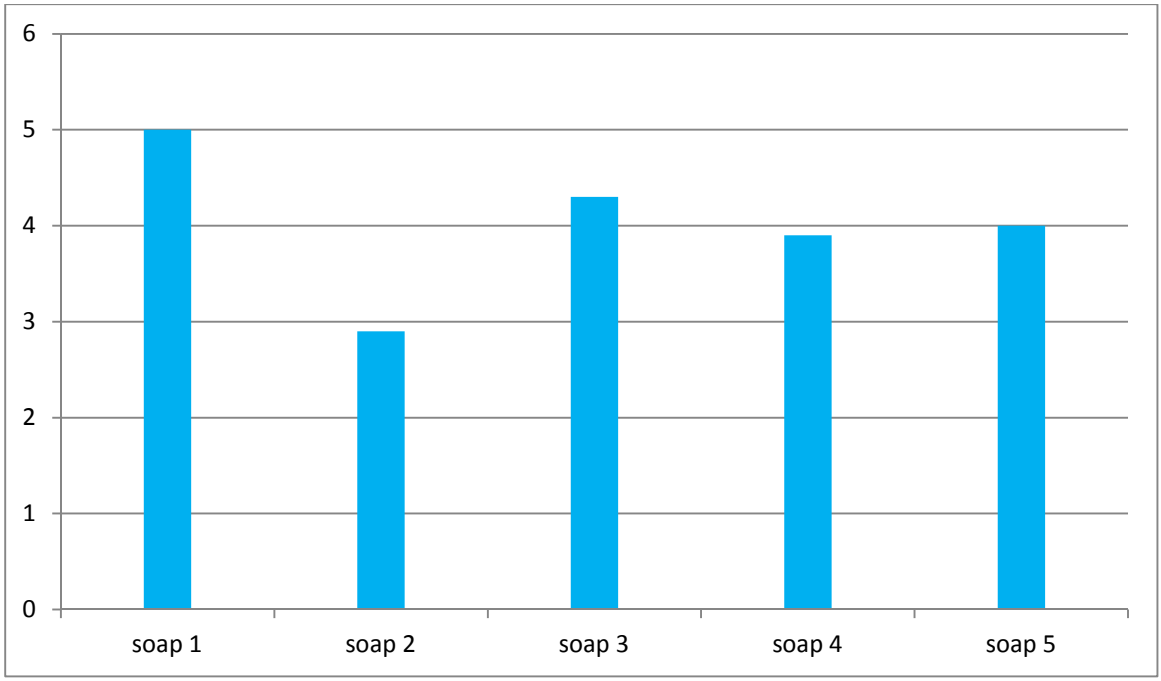
As can be seen from the graph, soap with a glue additive fared the worst. On cutting into the soap it was revealed that the soap had a denser composition compared to "normal" soap. Research into this soap was discontinued with a view to possible investigation in the future. It was unclear at this stage if the woolen fibres would interfere with any future aeration

procedures, and so it was deemed that the thinner cotton thread fibres would be preferable to use for the final insulation samples.

2.6.3: *Tensile Testing of the Combined Reinforced and Aerated Soap*

Aerated, reinforced soap samples were also used for the tensile testing and the results are shown in the table on below. The soap samples consisted of soap mixed as per the previous mixes, with the addition of cotton fibres for strength. The soap samples were aerated with straw, hollow plastic spheres, Expancel and the vacuum method as per the mixtures described in chapter 4.3-5. Once hardened the soap was tested to ascertain its tensile strength. All four samples performed worse than the un-aerated samples (shown in Fig. 6). The actual strength of each sample is recorded in Fig.7 below.

Fig. 7: Failure of soap graph. (Read, 2012)



Side numbers are tensile strength measurements in psi

Soap 1: control (added cotton fibres but not aerated)

Soap 2: Added hollow plastic spheres

Soap 3: Added straw

Soap 4: Added Expancel

Soap 5: Aerated via the vacuum method

The results indicate that aerating the soap samples decrease the tensile strength of the soap, even when the soap has been strengthened. This could be a result of the aeration process making the soap less dense, which in turn makes the samples less resistant to compressive force. The molecular bonding could be weakened because of the breaking up of the linear structure as the pockets of air decrease the structural integrity. The soap sample with the added plastic spheres fared the worst. This was because the soap failed to adhere the plastic to the same extent that it bonded to the straw and Expancel. Research into soap with the addition of plastic spheres was discontinued at this stage. However, research into the other three sample types was continued.

3. Conclusion

Soap samples were manufactured using the cold process described previously into this paper. Both fats/oils and lye were combined to create solid soap. The samples were strengthened with the addition of cotton fibres, wool fibres and natural polymer glue. The samples were also aerated to create lightweight products. The best performing samples will be hot-box laboratory tested to ascertain the U-values, and then then tested for thermal efficiency in real-world situations.

No definitive conclusions as to whether soap based insulation will perform can be made at this stage as the research is still ongoing. Soap based thermal insulation is a new concept and the soap development processes are still evolving. Early indications reveal that soap can perform as a thermal insulation, but at what constitution and thickness is still to be determined. The thickness of the insulation to its application ratio will be a key factor for determining if the insulation will be marketable.

4. References

Barret, E. (2012). The Chocolate Apprentice. Retrieved 24 October, 2012 from http://www.youtube.com

Bejan, A. (2004). *Convection Heat Transfer.* (p.150). Indiana: Wiley.

Celotex Wall Insulation. (2010) Retrieved from http://www.celotex.co.uk.

Chocablog. (2010). Galaxy Bubbles. [Weblog]. Retrieved 03 August, 2012 from http://www.chocablog.com.

Cohen, L., & Manion, L. (2000). *Research methods in education*. (5th ed.). (p.254). Oxon: Routledge.

Clegg, J., Payne, J.,& Sherry, J. (2002). *Success in Foundation Science.* (p.40). Dublin: Folens.

DeGunther, R. (2010). *Solar Power Your Home For Dummies* (2nd ed.). (p.179). Indiana: Wiley.

Expancel (n.d.) Safety Data Sheet. [Leaflet]. Sundsvall, Sweden.

Gooch, J.W. (1997). *Analysis and Deformulation of Polymeric Materials: Paints, Plastics, Adhesives and Inks.* (p.194). New York: Kluwer Academic.

Goodall, C. (2012). *How to Live a Low-Carbon Life: The Individual's Guide to Stopping Climate Change.* (p.231). London: Earthscan.

Grosso, A. (2002). *Soapmaking: A magickal Guide.* (p.51). New Jersey: New Page Books.

Grosso, A. (2003). *The Everything Soap Making Book: Learn How to Make Soap at Home With Recipes, Techniques and Step-by-Step Instructions.* (p.120). Avon: Adams Media.

ICAEN (Institut Catala D'Energia). (2004). *Sustainable Building Design Manual: Sustainable Building Design Practices. Vol.2*. (p.65). New Delhi: The Energy & Resource institute.

Joachim, D. (2001). *Brilliant Food Tips and Cooking Tips: 5000 Ingenious Kitchen Hints, Secrets, Shortcuts and Solutions.* (p.172). Pennsylvania: Rodale Press.

Journey to Forever. (2011). Making Lye from Wood Ash. Retrieved 02 February, 2011 from http://www.journeytoforever.org/biodieasl/ashlye.

Kirk,D. (1997). *Environmental Management for Hotels: A Students Handbook.* (pp.87, 88). Oxford: Butterworth-Heinemann.

Long, M. (2006). *Architectural Acoustics.* (p.335). California: Elsevier Academic Press.

MacKay, D.J. (2009). *Sustainable Energy-Without the Hot Air.* (p.5). Cambridge: UIT Cambridge Ltd.

Palmer, I. (2007). Perfume, Soap and Candle Making: The Beginners Guide. (p.4). New Sky Energy data sheet. (2009). Retrieved 09 September, 2011 from

http://www.cees.colorado.edu/carbon/little.

Pan Global. (2003). *Essentials for Power Engineering: plant and safety Theory.* (p.177). Boston: Pearon.

Rogers, H. (2005). *Gone Tomorrow: The Hidden Life of Garbage.* (p.162). New York: The New Press.

Ryan, C. (2011). *Traditional Construction for a Sustainable Future.* (p.178). Oxon: Spon Press.

Sustainable Building Sourcebook. (2010) Retrieved from http://www.cbserv.com.au.

Tro, N.J. (2012). *Chemistry in Focus: A Molecular View of our World.* (5th ed.). (p.375). California: Brooks/Cole.

Worrell, E. & Galitsky, C. (2005). *Energy Efficiency Improvement and Cost Saving Opportunities for Petroleum Refineries.* (Report 56183). Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, CA. Retrieved 20 July, 2012 from http://www. Energystar.gov/petroleum energy guide.pdf.