Foam Behavior in a Washing Machine Tumble Application

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Pressure from environmental groups as well as limitations on resources have pushed the society into developing more environmentally friendly products. Increasing energy regulations, such as Energy Star ratings, help reduce energy consumption. Companies need to keep their competitive edge through innovative products that satisfies the market demand. Foam cleaning in a washing machine has the potential to create an innovative product that reduces energy and water consumption while maintain the cleaning performance the consumer demands.

I. Why use foam cleaning in a washing machine?

Foam cleaning in a washing machine has the potential to save the consumer energy and water while maintaining or improving the cleaning performance. Current washing machines clean by completely submerging clothing in a low concentration, high volume mixture of water and detergent. Top loading washing machines (vertical axis rotation) use between 17 and 23 gallons of water during the wash cycle and between 34 and 49 gallons for the full wash/rinse cycle [1]. The load is completely soaked in water and the agitator rotates to clean the clothing. Front loading machines (horizontal axis rotation) use about 4 to 8 gallons for washing and between 15 and 32 gallons of water for the full wash/rinse cycle [1]. For front load machines, the drum is only partially filled with water and the load tumbles, much like a clothes dryer, through the water. Decreasing the amount of water used in the wash cycle will decrease water consumption as well as energy usage. “Most of the energy (80-90%) for laundering is consumed in heating water. Since only the wash water is normally heated, important energy savings result.” [1]

A high volume, low water foam has the potentially to replace the water fill used in the wash cycle of the front loading machine (4-8 gallons). The foam contains roughly the same amount of detergent as the regular water fill, but with much less water. The high volume of foam in combination with drum tumbling can potentially lead to uniform chemistry application on the clothes’ surface. Uniform chemistry application and detergent dosage are directly related to cleaning performance. Using foam as a method of cleaning in a washing machine has the potential to decrease energy and water consumption without sacrificing cleaning performance. Foam eliminates the need for the water fill in a wash cycle which decreases the amount of water needed per cycle. Since less wash water is needed, less energy is used to heat the wash water. Uniform coverage of the foam on the surface of the clothing load maintains or potentially improves cleaning performance.

II. What types of foams can be used in a washing machine?
Foam is defined as a two-phased system in which gas cells are enclosed by a liquid. Aqueous foams can be broadly characterized as 'wet' or 'dry' foams. 'Wet' foams have an aqueous volume fraction between 10% and 20% and typically contain bubbles with an approximately spherical shape. 'Dry' foams have an aqueous volume fraction less than 10% and contain bubbles with a polyhedral shape.

Foam cannot be created with purely water and air. "It is important to recognize that bubbles have no stability unless there is some barrier to prevent coalescence when two bubbles touch. This barrier is provided by the presence of a water-soluble surfactant. Pure water will never foam. In fact the presence of a foam, however small, on the surface of water is a certain indication of contamination."[2] Surfactants are the cleaning agent found in detergents that is responsible for creating foam. "The term *surfactant* is a blend of '**surf**ace **act**ing **a**ge**nt**'. Surfactants are usually organic compounds that are amphipathic, meaning they contain both hydrophobic groups (their 'tails') and hydrophilic groups (their 'heads'). Therefore, they are soluble in both organic solvents and water."[3] The hydrophilic 'head' is water soluble while the hydrophobic 'tail' is water insoluble. The hydrophobic end is attracted to soil molecules on the clothing surface which separates the soil from the clothing. The hydrophilic ends prevent the soil molecule from re-depositing back on the clothing (Figure 1).

Figure 1: *Surfactants are the cleaning agent found in detergent. Surfactants are amphipathic which allows the surfactant molecules to separate soil from clothing and prevent re-deposition*. [4]

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The evaluation of the foaming properties of soaps and detergents is a difficult problem because the volume and quality of the foam produced by any method from a given solution of a soap, detergent, or foam-forming material is a function of many complex factors. John Ross and Gilbert Miles from Colgate Palmolive Peet Company developed a standardized test method to measure the foaming properties of soaps and detergents, shown in their study titled "An Apparatus for Comparison of Foaming Properties of Soaps and Detergents".[5] The solution being tested is placed in a small pipette above a receiving reservoir. An orifice at the bottom of the pipette breaks the solution into droplets. Foam is produced when the droplets strike the surface of the liquid or foam in the receiver. The height of the foam was measured and taken as proportional to the volume of foam, assuming the cylinder is uniform in cross-section. The volume of foam formed is a linear function of the volume of liquid added, no matter which detergent is tested (Figure 2). Figure 3 and Figure 4 illustrate the characteristic relationship between detergent concentration and foam production for several detergents. Foam production increases with increasing concentration until it levels off near a concentration of 0.25% soap, except for synthetic detergent A and sodium laurate. Detergent A appears to level off near 0.75% while sodium laurate is still increasing at 0.35%. This variation may be due to a discrepancy in the amount of surfactants present in each of the soap solutions. This study shows that the volume of foam created is heavily dependent on the type of detergent used as well as the concentration.

Figure 2: *The volume of foam formed is a linear function of the volume of liquid added, regardless of which soap is used.* [5]
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Figure 3: *Relationship between detergent concentration and foam production for tallow soap, olive oil soap, and synthetic detergent.* [5]
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Figure 4: *Relationship between detergent concentration and foam production for sodium palmitate, stearate, myristate, and laurate.* [5]
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III. Do any current consumer washing machines clean with foam?

No consumer washing machines currently on the market use foam as a primary means of cleaning during the wash cycle since. Engineers today think of foam as a negative substance in a washing machine. A washing machine is designed to clean clothing both chemically and mechanically. The detergent solution cleans clothing chemically while the tumbling or agitating action cleans the clothes mechanically. Unwanted foam created in current water fill machines decreases the mechanical action of clothing rubbing against each other which in turn decreases cleaning performance. In the worst case, foam my actually overflow from the machine. In contrast, the majority of consumers relate cleaning ability to the presence of foam. “In general, foam is an indication that the product is performing its intended task; foam disappearance is a signal that the product has fulfilled the requested performance and that its detergency or cleaning potential is exhausted…in most cases foam is not essential to the performance of a product.”[6]

Many methods currently exist to eliminate or control foam production in washing machines. Many washing machines have built in methods to eliminate foam. Wash cycles can be manipulated to include timed sprays that eliminate the foam formed during the wash process [7]. Another such method is the addition of silicone polymers into detergent as foam controlling agents. The silicone solution contains hydrophobic silica particles which spread across the surface of the foam. Surfactant molecules move to the exposed silica particles to reduce the interfacial surface tension between the hydrophobic silica and aqueous medium, thereby decreasing the concentration of surfactants. As they move to the hydrophobic silica particles, the surfactant molecules will drag the water associated with their hydrophilic heads, causing localized thinning of the foam film. The combination of film thinning and reduction in surfactant concentration is sufficient to cause the film to rupture and foam to collapse [8].

IV. Is foam cleaning in a washing machine plausible?

Foam is currently thought of as a negative quality in a washing machine. This is due to the effects of unwanted foam during the wash process. If foam production can be controlled, it has the potential to be an effective and efficient wash process.

In order for foam to be even considered as an appropriate cleaning method, it must be proven that foam can maintain or improve cleaning performance of fabric when compared to current detergent solutions. Bench-top testing (conducted outside of the washing machine) has proven that cleaning with foam is comparable to cleaning with regular detergent [9]. Swatches containing a variety of soil stains were soaked in a detergent-water mixture while separate identical swatches were covered in foam contained an equal amount of detergent. The test results showed minimal difference between test cases which shows foam cleaning has the potential to maintain cleaning performance.

Foam cleaning in a washing machine is plausible but not without overcoming some obstacles. A main problem with foam in a washing machine is that the mechanical action of tumbling clothes breaks down the foam into a high-concentrated, low-volume liquid before the foam has had a chance to uniformly cover the clothing load. Uniform coverage is crucial to cleaning performance and is easy obtained by mixing the foam solution by clothes tumbling. US Patent 1,948,568 titled “Method of Treating Textile Materials and the Like” describes an invention of cleaning textiles with foam and with minimal or no tumbling [10]. Figure 5, 6, and 7 show different forms of the foam cleaning invention described in the patent. The apparatus in Figure 5 does not use mechanical action to clean textiles. The fabric is placed in the tub and foam is created and pushed through the orifices in the center rod, labeled 15. Figures 6 and 7 show a device that rotates around the center axis. Foam is created and pushed through orifices located along the center axis. Figure 6 shows separators which keep textiles flat while pushing foam through the fabric to maximize cleaning performance.

Figure 5: *No clothing tumble, foam cleaning apparatus.* [10]
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Figure 6: *Textiles place between separators and foam is pushed through fabric while machine is rotating*. [10]
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Figure 7: *Rotating clothes tumbler, foam cleaning apparatus.* [10]
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US Patent 4,118,189 titled “Method of Washing Textiles” also addresses foam cleaning, but this time for use in a tumbling washing machine [11]. “An objective of the present invention is the development of a washing method which permits the use of high detergent concentrations with a corresponding high quality washing result, while saving water both in the main wash cycle and in the rinse cycle, and as a result saving heating energy.”[11] The method described in this invention is as follows: (1) contact soiled textiles with a foamed detergent solution; (2) agitate soiled textiles with foamed detergent solution for at least 30 seconds; (3) separate foamed detergent solution from textiles by breaking down the foam using mechanical action; (4) recover previous detergent solution and foam again; (5) repeat steps (1) to (4) from five to 50 times; (6)

rinse textiles. The foam is delivered to the tub through a feeding system in the back of the unit (Figure 8). The drum rotates slowly spread the foam uniformly over the clothing load. After the foam has been applied to the load, the foam is destroyed by briefly spinning and the soilladen detergent solution formed by the decomposition of the foam is partly removed to be used again in the next foam cycle. Ten to 30 cycles of the foaming and destroying process should be completed to obtain desirable cleaning results. "The destruction of the foam…requires only relatively minor centrifugal forces. In general, a centrifugal force which is about five times to twenty times the amount of the acceleration due to gravity is completely sufficient for the intermittent spinning. To this end the conventional drumtype washing machine with a diameter of about 35 to 80 cm and spinning speeds of about 60 to 400 rpm are quite adequate."[11]

Figure 8: *Method for introducing foam into a washing machine. Air pumped in through a nozzle 5 mixes with detergent-water mixture at 7. Foam is created and enters the drum 2 at port 13. The foam is then broken down back into liquid form and returns to the reservoir 10. The filter 11 removes soil particles and the process repeats.* [11]
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Washing tests were conducted to compare the cleaning results using the foam cleaning method verse traditional cleaning. The results clearly show the superiority of the foam washing method previously described when compared to traditional cleaning methods (Figure 9 on page 9).

The two inventions described earlier were patented in 1930 and 1978, respectively. Even though these inventions were created many years ago, there are still no consumer washing machines that use foam as a primary source of cleaning. Factors exist that may impede the use of foam cleaning even if it reduces energy usage and water consumption while improving cleaning performance. Some of these factors include: (1) Cycle Time – the use of foam may increase the total time it takes to complete a wash cycle; (2) Cost – the addition of foaming components and recirculation systems may increase the unit cost; (3) Health Issues – foaming of detergent solutions may pose the risk of inhalation of unwanted chemicals.

Figure 9: *Results of comparison of foam cleaning verse traditional cleaning. The comparison example represents traditional cleaning. The higher the remission percentage, the better the cleaning (100% complete cleaning, 0% no cleaning). Slightly soiled swatches were tested: "c" cotton; "f.c" wash-and-wear finished cotton; "p.f.c" blends of polyester and finished cotton. The results clearly show the superiority of the foam washing method previously described when compared to traditional cleaning methods.* [11]
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V. What other factors in the wash process effect foam creation?

Concentration of detergent, as previously discussed, is one factor that determines foam creation. Some other factors include types of stains, amounts of soil, temperature of water, and water hardness. W. G. Spangler of Colgate-Palmolive Company studied these factors in report titled "Dynamic Foam Test" [12]. A machine called a tergotometer was used to simulate conditions in a washing machine on a smaller scale. Photographs were taken over intervals of soil addition to observe changes in the level of foam with soil. The typical soils used were sebum (human oil secreted out of the sebaceous glands) and fat (hydrogenated vegetable oil).

Figure 10 on page 10 shows the results of a test comparing different detergent concentration (0.05% to 0.20%) with different soil levels (0 mg to 500 mg of sebum). The top picture (with no sebum added) shows that the initial foams have very little difference in volume in spite of the concentration variations. After 200 mg of sebum was added to the containers, the 0.05% foam completely collapsed. After 500 mg of sebum was added, the 0.20% concentration was the only container to not show a decrease in foam. Since the composition of detergent used contains 25% Active Ingredient, the maximum tolerance for 10 mg of detergent is 50 mg of soil, for this particular system [12].

Temperature also has an effect on the destruction of foam. Figure 11 on page 10 shows the test results comparing different temperatures (80 to 140 degrees F) to soil amount (0 mg to 300 mg) for two different soils (sebum and fat). As you can see from Figure 11, the sebum contaminated solution collapses at lower temperatures while the fat contaminated solution collapses at higher temperatures. Temperature does have an effect on foam collapse, but it is depended on the type of stains present.

Figure 10: *Compares different detergent concentrations to different soil levels. Lower detergent concentrations cause the foam to collapse with lower soil levels.* [12]
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Figure 11: *Foam collapse for two different soils (sebum and fat) at different water temperatures and soil dosages. Sebum appears to collapse foam at lower temperatures while fat collapses foam at higher temperatures.* [12]
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Another important consideration in aqueous cleaning is the amount of calcium and magnesium present. Figure 12 below and Figure 13 on page 12 show the difference between foam breakdown in hard water and in soft water in the presence of fat and sebum. Four different detergents were tested (A, B, C, and D) in soft water containing 50 ppm calcium carbonate and hard water containing 300 ppm calcium carbonate. Two types of soils were used (sebum and fat) with soil amounts ranging from 0 mg to 600 mg. Product A was better in soft water then hard water for sebum but just the opposite in the presence of fat. Product B collapsed completely for each soils with both soft and hard water. Product C had minimal foam reduction with soft water for both soils, but collapsed completely in hard water. Product D showed no foam collapse by 600 mg of fat for both soft and hard water, but collapsed completely with sebum. This study shows that hard water has an effect on foam collapse, but that it is greatly dependent on the type of detergent used.

Figure 12: *Foam collapse in the presence of sebum for hard and soft water. The hardness level of the water effects foam collapse differently for each type of detergent (A, B, C, and D).* [12]
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Figure 13: *Foam collapse in the presence of fat for hard and soft water. The hardness level of the water effects foam collapse differently for each type of detergent (A, B, C, and D).* [12]
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In laundry applications, the presence of fatty or greasy soils is not as important as the sebaceous secretions. Therefore, most of the testing work in centered on results using only synthetic sebum. "…soil of the average wash load is made up of 5-10% sebaceous material (excluding skin scales). It is estimated that a minimum secretion of sebum for the whole body in a day is about 0.3 g."[12]

VI. How can foam be created in a washing machine?

Foams can be created in a number of ways [13]:

(1) Blowing gas through a thin nozzle into a liquid;
(2) Sparging (blowing gas into a liquid through a porous plug;
(3) Nucleation of gas bubbles in a liquid which is supersaturated;
(4) Shaking or beating the liquid.

Unwanted foam in front load tumbling washers is created as a result of the movement of the fabric loud out of and back into the water bath. The load is continually being dropped onto and through the water surface. Breaking of the water surface allows air to be trapped in the detergent solution, creating suds, or foam. This method of creating foam is not efficient because it does not reduce the amount of water needed in the wash process.

The simplest way of creating foam in a washing machine would be to generate foam through a nozzle. US Patent 1,948,568 describes a simple and effect means for creating foam in a washing machine application, shown if Figure 8 on page 8 [11]. A line is connected to a detergent-water reservoir which leads to a nozzle, where fresh air is introduced. Pressure in the line causes the water solution and air to mix at the nozzle, creating foam.

Sparging is another possible method for creating foam in a washing machine. Some current foam machines work by covering a thin mesh with a detergent-water mixture and blowing air through it, creating bubbles and foams. This application has the potential to work in a washing machine application, but it is more complicated and requires more parts than a simple nozzle design.

VII. Does foam cleaning in a consumer washing machine have the potential to become an innovative process?

Foam cleaning does have the potential to become a new feature on consumer washing machines. Current trends in the US market show more environmentally friendly and energy conscious products. Energy Star ratings are becoming more important when consumers purchase their appliances. Foam cleaning has the potential to reduce water and energy while maintaining or possible improving cleaning performance.

Foam has a large potential for the global market as well. The European market is already much more energy efficient than the United States market. The complete cycle time in Europe is significantly longer than the cycle time in the United States due to the energy requirements that must be met while heating the wash water. Foam has the potential to decrease the cycle time in Europe since less water will be needed for heating.

Foam has the potential to be a ‘wow’ factor in the market. Even if foam cleaning does not provide any benefits, the consumer still associates foam with cleaning and may buy the product for that feature. For example, a new feature on washing machines is the ability to steam clean. Testing shows that steam cleaning in a washing machine does not provide any substantial benefits, but the units are still selling well because consumers associate steam with cleaning.

Foam cleaning has the potential to improve cleaning performance in the washing machine. Studies show that foam cleaning shows a performance improvement, but only under the right conditions and with the right cycle modification (see Figure 9 on page 9). Extensive research must continue in order to fully understand the potential of foam cleaning in regards to cleaning performance.

There are some drawbacks to the use of foam cleaning in a washing machine. Limited information exists about foam used as the primary cleaning method in a washing machine. There may be some health issues with the inhalation of chemicals. Foaming may breakdown the detergent chemicals which could be inhaled. Not enough research is available to fully understand if this is actually a health risk. If so, the drum seal may have to be redesigned to prevent these harmful chemicals from reaching the air or the detergent will have to be reformulated for safety reasons.

Another issue that is not fully understood is the exact cycle needed for foam cleaning. Multiple foaming and de-foaming cycles may be necessary to maintain cleaning performance. The exact number of cycles is unknown for each type of load. A large, heavily soiled load may take many foaming cycles which could potentially increase the cycle time to more than a traditional wash cycle. Another unexplored issue is regarding the rinsing process. Since foam cleaning will deposit a higher concentration of detergent on the fabric, more water may be needed in the rinse cycle to completely clean out the detergent from the fabric. The additional water in the rinse cycle may cancel out the water reduction with the use of foam in the wash cycle which means there will be no water reduction benefit to foam cleaning.

Overall, foam cleaning has the potential to be an innovative feature in consumer appliances. The potential benefits of water and energy savings have large impact on the environment as well as in the consumer market. The negative aspects of foam cleaning are generated from the lack of knowledge of the effects. Foam cleaning in a washing machine should be continually studied in order to fully understand the process and someday implement into a consumer product.

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