GE Global Research

Energy Efficient Laundry Process

Final Project Report for the Department of Energy

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Abstract

With the rising cost of energy and increased concerns for pollution and greenhouse gas emissions from power generation, increased focus is being put on energy efficiency. This study looks at several approaches to reducing energy consumption in clothes care appliances by considering the appliances and laundry chemistry as a system, rather than individually.

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Acronyms and Abbreviations

ATC .... Automatic Temperature Control (dryer)
CFD .... Computational Fluid Dynamics
CTQ .... Critical to Quality
CW .... Cold Water
DAQ .... Data Acquisition System
DOE .... Department of Energy
EKF .... Extended Kalman Filter
EOC .... End of Cycle (4% RMC in dryer)
FMC .... Final Moisture Content
GE .... General Electric Company
GRC .... GE Global Research Center
HA .... Horizontal Axis
HW .... Hot Water
MDC .... Mass of Dry Clothes
MR .... Medium Restriction (Dryer vent = 2-5/8" opening)
NR .... No Restriction (Dryer = 3-3/4" opening)
P&G .... Procter & Gamble
RH .... Relative Humidity
RMC .... Remaining Moisture Content
SR .... Small Restriction (Dryer vent = 1" opening)
SS .... Stainless Steel
TL .... Tide liquid detergent
TP .... Tide powder detergent
VA .... Vertical Axis

Symbols

r .... Radius
r_b .... Basket inside radius
σ .... Surface tension
ρ .... Density
θ .... Angle
W_c .... Test Cloth Final Weight
W_i .... Test Cloth Initial Weight

1 Executive Summary

The largest impact to energy efficiency in the washing machine is water extraction. Any moisture remaining in the clothing is passed to the clothes dryer where the removal has a higher energy cost. The resulting solution to reducing the moisture at the end of the wash cycle was by improving the ribbed basket design. The ribs had a 20% RMC improvement as compared to the baseline smooth plastic basket.

The dryer system investigated several process techniques in addition to sensing and control. The process techniques, such as reversible drum, variable speed drum & fan, proved to be insignificant in effecting energy savings. Basic control techniques provided no energy savings and the effort focused on advanced control algorithms and sensor implementations. The final energy savings averaged 8% with one case as high as 17%. This gain was achieved by improving the end-of-cycle determination.

Procter & Gamble (P&G) also contributed to the findings of this report. P&G explored chemistry additives that would enable faster evaporation rates in the dryer and increase moisture extraction in the washer. In the dryer, evaporation could be improved, but the concentrations and delivery methods required were incompatible with consumer requirements. Silicone surfactants were found to reduce RMC by over 20%, however, compared to existing market products, this improvement was not sufficient to initiate new product development.

The remainder of this report will introduce the current products and processes used in laundry appliances and describe the approach to improve energy efficiency.

2 Introduction

Nearly one-half of all energy consumed during the laundry process is in the form of hot water. About 40% of the total energy is used for heating the air in the dryer and the remaining 10% is used to power the motor and control systems. There are several opportunities to reduce the energy usage for the clothes washing process.

The obvious energy reduction opportunity for the washer machine is hot water reduction. Reducing the volume of hot water is beyond the scope of this project and the temperature is fixed by DOE standards. Advances in laundry chemistry will one day enable effective low temperature detergents for significant energy savings.

A second opportunity for improving energy efficiency via the washing machine is by improving water extraction. The amount of moisture remaining (RMC) in the clothes after the final spin cycle in the washer is transferred to the dryer and must be removed by evaporation. Reducing the RMC reduces the heat required during the drying cycle. The goal of this project is to reduce RMC by 20% from the baseline washer.

Water extraction can also be affected by chemistry. The primary force holding moisture in the clothing fabric is capillary action. Small pores and channels in the fibers create large capillary forces that cannot be overcome by the centrifugal forces of the spin cycle. A prime driver of capillary action is surface tension of the water. Using chemical additives, the surface tension can be reduced, improving the water extraction.

With regard to the drying process, a significant amount of energy is wasted in over drying clothing. Current sensor and controls technology for dryers is fundamental, at best, and lacks the discernment required to accurately stop the process at the proper time. The result is excessive heat usage and longer dry times for the consumer. Also, excessive cloth temperatures can cause shrinkage of clothing. Various control algorithms and sensor arrangements will be applied to reduce overdrying and to improve the efficiency of the drying process.

One challenge of reducing energy efficiency is the need to commercialize the technology. It is difficult for appliance manufacturers to market and sell appliances solely on energy efficiency. The approach of this project is to keep in mind customer requirements (CTQs), one significant CTQ is overall cycle time, more specifically, dry time.

3 Washer Technology

In 2004, the US Department of Energy issued a new energy standard that included energy used for the drying process into the energy metric for washing machines. Appliances that extract more water from the clothes during the spin cycle will enable lower energy usage by the dryer. This section focuses on the reduction of retained moisture through basket modifications.

3.1 Washer Configurations

Shown below are two clothes washing machine, a GE Profile™ top-loading washing machine on the left and a GE Profile™ front-loading machine on the right.

Figure 1: GE Profile washing machines

a) VA b) HA

The major components of the washer machine are the basket, the tub, motor/transmission, and pump. Figure 2 illustrates these components (motor not shown for clarity).

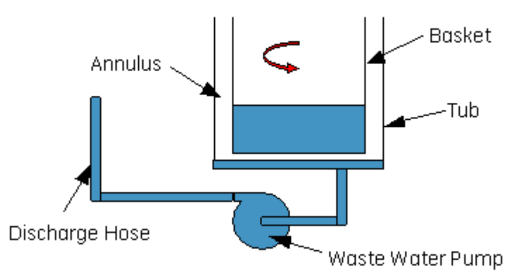


Figure 2: Washing Machine Components

3.2 Energy Usage

Energy is consumed in various means by the washing process. Electricity is required to power the motor for spin and agitation and for the automatic controls. Hot water energy is used is heating water from the house supply.

The recent trend for energy conservation has been to develop washers that utilize less hot water. Horizontal-axis (HA) or front-loading washers use less water than conventional top loading or vertical axis (VA) machines and have been gaining market share. HA machines are still considerably more expensive than conventional top-loading machine (VA) and have longer cycle times than VA machines. HA machines currently have limited market penetration with about 15% of washer sales being HA[1]. This project focuses on improvements for traditional VA machines.

H-G Hloch[2] (WKF Research Institute for Cleaning Technology, Kerfeld, Germany), states, "The mechanical dewatering of textiles by centrifugation shows extreme cost advantages compared to energy and time-intensive water removal by tumble drying." Only about 15% of the energy used in the drying process is due to the mechanical action of the washer. Extending the spin time or increasing spin speed comes with a very low energy cost.

The DOE measures washer efficiency using the modified energy factor, of MEF[3]. MEF is defined as the ratio of clothes load to energy usage. According to GE experiments, approximately 40% of the laundry process energy is used by the dryer, 50 by hot water usage, and 10% in electricity for the washer motor and controls. The dryer energy is impacted by the amount of water remaining in the clothing after the final spin of the wash cycle. This water content, or Remaining Moisture Content, RMC, is defined as the amount of water, by weight, which remains in the clothing tested, shown as a percentage of the bone-dry weight of the clothing in Eq. 1.

$$RMC = \frac{W_c - W_i}{W_i} \cdot 100 \qquad \text{Eq. 1}$$

3.3 RMC Reduction

The largest impact to efficiency is RMC that directly impacts ½ of the energy usage in the laundry cycle. Hot water usage is outside the scope of the DOE agreement. Pursuing efficiency gains with motor and drivetrain research has limited potential as these components consume only about 10% of the total energy for the laundry process.

For all testing, standardized DOE energy tests cloths, from Textile Innovators, were used. Baseline results were obtained using an unmodified production automatic washing machine containing a smooth plastic basket.

3.3.1 RMC Drift

The Department of Energy defines a standard method for preconditioning energy test cloths. General Electric began experimentation using this method, but quickly discovered unexpected trends in the collected data. A significant drift in RMC can be measured as the cloth wears. Procter & Gamble also observed this phenomenon.

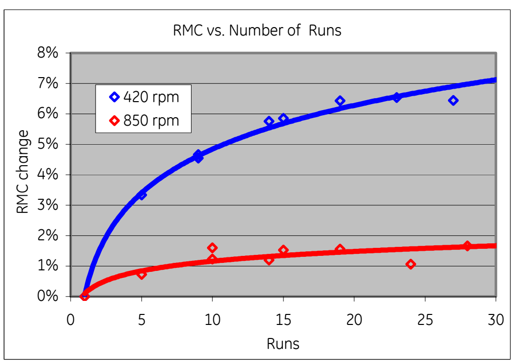


Figure 3: RMC drift vs. run count

To compensate for this drift, periodic baseline measurements were taken and used to adjust the RMC measurements appropriately. A modified preconditioning method was also used, effectively adding more cycles to the cloth before collecting data. This placed the cloth in the flatter section of the wear curve.

In January 2004, the DOE released an updated Appendix J1 detailing a new preconditioning method to reduce this drift. The work from this project supports the need to modify the standard. The reader can be confident that all experimental results contained within this report are generated with consideration for this known drift.

3.3.2 Spin Speed

The spin cycle is the most cost-effective means for drying clothing. Water is "pulled" from the clothing by centrifugal force generated by the spinning basket. Fast spin speeds will remove more water, as shown in Figure 4.

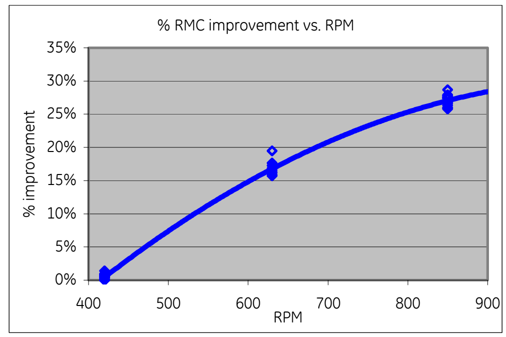


Figure 4: RMC improvement vs. RPM

While increasing spin speed is one way to reduce the RMC of cloths, the improvement comes at a price. Driveline components such as the bearings, transmission, and motor must be oversized. In addition, the basket may require a redesign to handle high hoop stresses and out-of-balance loads. The higher cost precludes introduction of the technology into the majority of the washing machine market consisting of low and mid-level machines.

3.3.3 Spin Time

Spin time also has an impact on RMC. While the product cost does not increase, the cycle time "cost" will increase. A customer objective when doing laundry is time and increases to the overall cycle time of the process are not desirable.

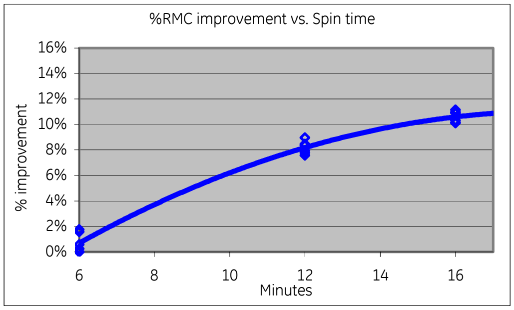


Figure 5: RMC Improvement vs. Spin Time

Because of the added costs of increasing spin speed and time, an alternative method to improving water extraction is desired. A method that takes advantage of capillaries within the clothing will be presented.

3.3.4 Capillary Action Theory

The height of water in a capillary is a function of the capillary size and surface tension of the water. There are three main capillaries in the clothes load. The first are the large capillaries between fabrics. Very little water is retained in this region. Next, capillaries are formed between the threads of the fabric. Lastly, the smallest capillaries are within the cloth threads and fibers. These produce the strongest of capillary forces.

Capillary forces can be described the equilibrium height of the liquid in the capillary tube, as in Eq. 2 and Figure 6.

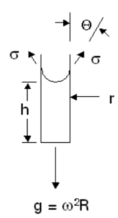


Figure 6: Capillary Illustration

$$\mathbf{h} = \frac{2\sigma\cos\Theta}{\rho_w \mathbf{rg}} \qquad \text{Eq. 2}$$

Laboratory experiments have shown an influence on capillary height when mechanical compression is applied to fabric samples. Untouched fabric was suspended with one end immersed in water. After reaching equilibrium, the capillary height was recorded. The samples were then mechanically compressed using a clamp to reduce capillary size. The samples were again suspended and capillary height measured. A third experiment was performed wherein the clamp remained on the cloth samples.

Control of the clamping force is nearly impossible, so actual height measurements were not recorded, but the resultant trends are nonetheless relevant. It was found that increasing the clamping force increased the capillary height. This was most significant where the clamp remained on the sample while immersed in water.

The conclusion from this experiment is that increasing the compression of the clothing changes the balance of capillary forces within the cloth. By adding a means of compression at the basket wall, water extraction can be improved. This compression can be achieved by using a ribbed basket configuration such as those described by Hitachi.[4]

3.3.5 Current Production Basket Configurations

The basket contains the clothing and spins during the spin cycle. The basket is perforated and is placed inside the tub, which holds the water. The perforation of the basket provides an egress means for soil and water. The basket in Figure 7 is a smooth plastic basket found in the economical washing machines offered by GE.

Figure 7: Smooth GE Plastic Basket

General Electric also offers a ribbed plastic basket with 24 ribs, aimed at the mid-level market. The ribbing pattern improves water extraction over the smooth basket, but the design is not optimal.

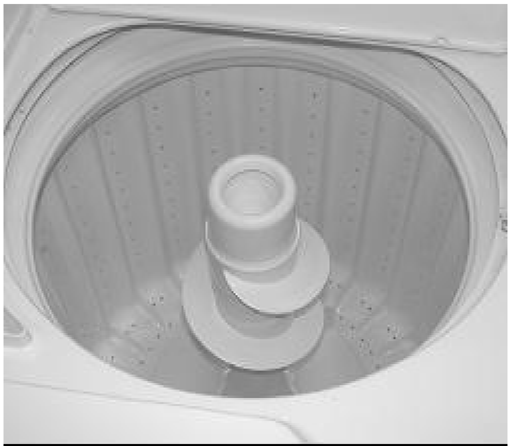


Figure 8: Ribbed Plastic Basket

To address the higher-end retail market, GE offers a stainless steel basket with 20 sets of small ribs. The SS basket allows higher spin speeds because of its increased strength over a plastic molded basket. SS also has a look and feel that is more pleasing to customers.

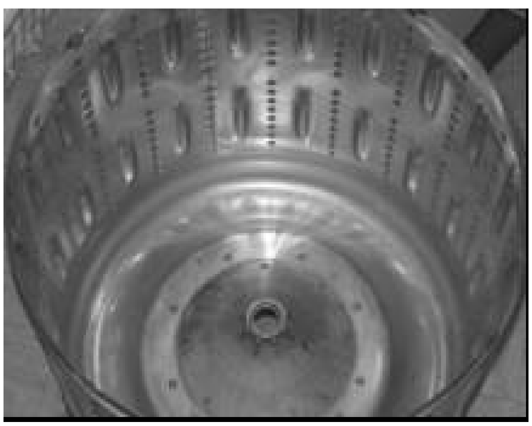


Figure 9: GE Stainless Steel Basket

3.3.6 Rib Experiments

In pursuit of an improved rib design, various parameters of the system were identified as potential factors as illustrated in the fishbone diagram, below. Based on experience and screening experiments, the factors highlighted in bold lettering were selected as the primary contributors to RMC.

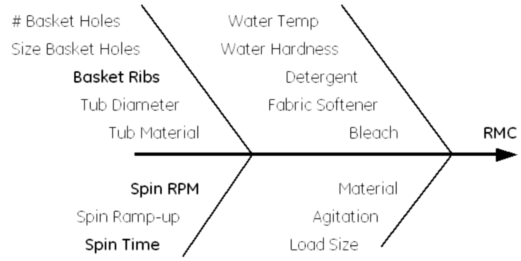


Figure 10: RMC Influences

TEST BOX

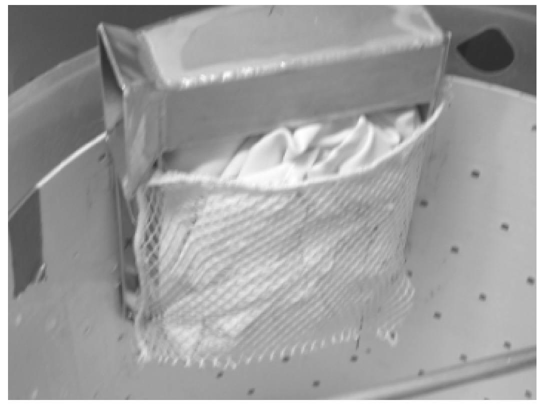


Figure 11: Subscale Test Box

The first experiments were conducted using a subscale test box. Experiments were performed with various rib spacing, rib height, rib material, and airflow strategies. The results were used to steer successive tests leading to full-scale prototypes. Up to the equivalent of 48 ribs was installed in the test box, twice that of the current production ribbed basket. The results from the test box experiments showed that more ribs and larger ribs improved water extraction. To validate the prediction, a full-scale basket was assembled.

FULL-SCALE PROTOTYPE

A full-scale basket was outfitted with tubes fastened with self-adhesive clips, shown in Figure 12. The tubes simulated ribs that could be molded into the plastic basket.

Figure 12: Smooth Basket with tubes

During scale-up, there were some disconnects between the subscale test box results and full-scale results. Based on this finding, it was decided that the test box results could help steer direction, but that unknown factors were driving variation from the full-scale prototype. Testing proceeded with full-scale prototypes to ensure realistic comparisons to the baseline.

It was also determined that investigation of rib effects at 850 rpm would be needed. For full scale testing, a stainless steel basket would be required as the plastic baskets are not capable of such high spin speeds. Several stainless steel baskets were fabricated without the ribs found in the production baskets. These smooth baskets would serve to hold various shapes and materials for simulating ribs.

3.3.7 Airflow Management

During the spin cycle, moisture is also removed from the clothing through evaporation. This section summarizes the work done to quantify the benefit of enhancing evaporative means.

The basket and agitator naturally form a centrifugal pump and air can be forced across the clothing to aid in water transport from the cloth. Air channels could also be located within new rib configurations, potentially improving the process.

The influential factors are: incoming air RH, airflow, load size, and spin time. Because the details of evaporation rate are difficult to define, a simplified heat transfer model was created. The difference of outlet and inlet air temperatures defines the rate of evaporation, so a lower outlet air temperature means more heat has been used during evaporation of more water[5].

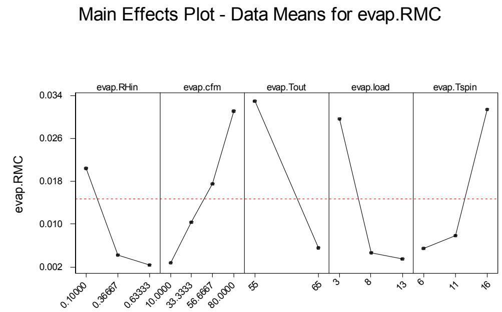


Figure 13: Evaporative Effect Main Effects

The primary factors are airflow, outlet air temperature and spin time. A wide range of operating points was generated and analyzed.

Figure 14 summarizes the relative frequency of benefits, where the x-axis shows absolute RMC% improvement. Only one point at 10% inlet RH, 80 CFM, 55°F outlet air, 3-pound load and 16 minute spin time showed significant benefit. It is unlikely this operating point would be practically achieved with any frequency in commercial or household conditions.

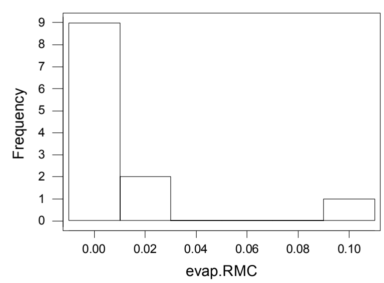


Figure 14: RMC Improvement due to Evaporation

Given the limited benefits from this screening analysis, further pursuit of evaporative drying in the spin cycle was not pursued.

3.3.8 SS Production Prototype #1

At this point in the project, test box experiments and full-scale experiments had been completed. Evaporative effects were not significant and would not be included in the prototype design. A maximum of 48 ribs were tested at a maximum height of 5/8". This configuration showed the best performance.

In order to demonstrate suitability for manufacturing, customer requirements were gathered and manufacturing costs were considered.

Stainless steel usage in appliances has grown quickly in recent years. The look, feel, and perception of quality of stainless steel has won market share from plastics. Nearly all high-end appliances are made with stainless steel, whether it is the appliance enclosure or internal components. This material choice is quickly being introduced to mid-level appliances.

Modifying the injection molded plastic basket would require a relatively simple analysis and a tooling change to incorporate rib changes. Stainless steel presents many additional complications such as forming limits and material thickness tradeoffs. Therefore, the first prototype would be built from stainless steel. There are a several advantages of SS construction beyond customer satisfaction, such as higher spin speed capabilities and slight improvements in RMC.

A corrugated liner was formed from sheet stainless steel using a press brake and custom tooling. The liner was bent into a cylinder and inserted into a smooth stainless basket and riveted in place. The configuration is not suitable for a production basket because of the excess material weight, but works well for testing.

Figure 15: SS Prototype #1

Once the new SS insert was placed and affixed to the standard SS basket, it was then placed into the test machine for testing to begin. The results of this initial SS insert were quite interesting, and show that there was an improvement from the SS basket without ribs, and especially over a smooth plastic basket.

Figure 16: 1st SS insert in test machine

Figure 16 shows the prototype SS basket installed in the washing machine. Compared to the smooth SS basket baseline, the corrugated insert improved RMC by 12% at 630 rpm and 19% at 420 rpm. Testing at 850 rpm was not performed to prevent risk of damage if the prototype were unbalanced.

3.3.9 Additional Rib Experiments

While the first SS insert was being fabricated, analysis of the RMC data showed additional data points were needed, specifically in higher rib count and taller rib size. Based on impacts to customer requirements, mainly capacity, a 1" upper limit was set for rib height. A small rib of ¼" was chosen to investigate the opposite extreme. A rib spacing of 7, 3, 1, and 0 would be tested as it was expected that as rib count approached the maximum, a reduction in benefits would be observed, as the surface would approach a smooth basket.

To normalize the spacing, or rib count, across different rib sizes, rib density is defined:

$$\mathbf{RibDensity} = \frac{\mathbf{x}_R}{\mathbf{x}_R + \mathbf{x}_s} \qquad \text{Eq. 3}$$

$$\mathbf{x}_R + \mathbf{x}_s = 2\pi \mathbf{r}_b$$

where x_R is the rib width and x_S is the distance between ribs.

RMC tests were performed at 420, 630, and 850 rpm, the results for 630 rpm are plotted in Figure 17.

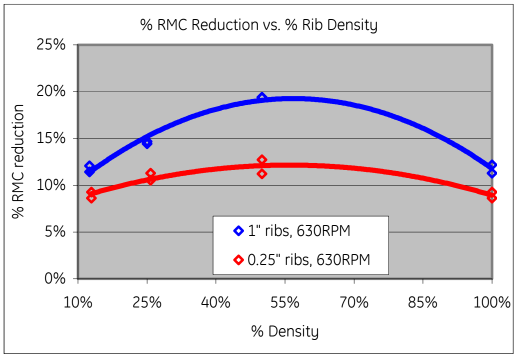


Figure 17: %RMC reduction vs. % Rib Density at 630RPM

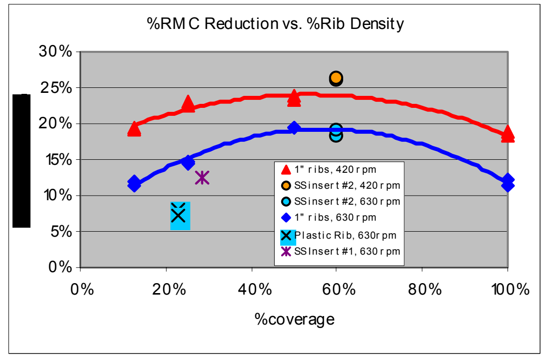


Figure 19: RMC Reduction

There is a clear advantage to using 1" ribbing in the basket design and the optimal rib density is near 60%. Perhaps a taller rib could help improve this further, though the impact on capacity must be kept in mind.

Figure 17 shows a maximum improvement of nearly 20% benefit. Increasing the density reduces benefits as the basket shape approaches the smooth basket and the effective diameter decreases.

In the 420RPM case, the percentage gain for RMC was 24% for the 1" Rib case, and 20% for the 0.25" rib case. This indicates that at low RPM, the ribs have a better effect on improving RMC.

3.3.10 Final Prototype Basket

The additional rib experiments directed the configuration of the final prototype. This prototype would also be constructed from stainless steel, but would be configured based on the data collected in section 3.3.9.

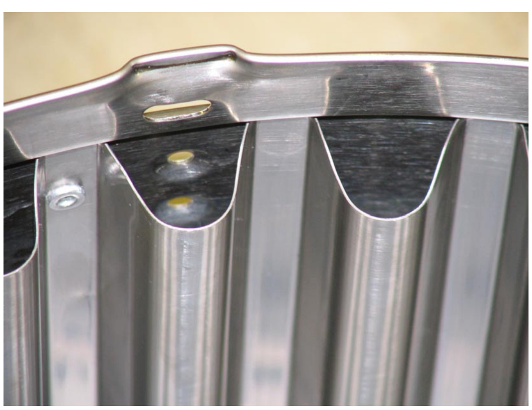


Figure 18: SS insert #2 with Balance Ring Removed

The new basket performed as predicted, closely matching the 630rpm prediction and exceeding the 420rpm prediction.

Figure 19 shows the RMC of the 2nd prototype basket overlaid on prior experimental data and includes a data point showing the performance of the production plastic basket at 7-8% above the smooth basket baseline.

3.3.11 Overall RMC

Overall RMC is a weighted average of the RMC values for minimum and maximum spin speeds. Based on DOE test procedures and standards, RMC is calculated as shown in Eq. 4, where RMC_{low} is the RMC for the low spin speed (420 rpm) and RMC_{high} is the value for high spin speed (630 rpm).

$$\mathbf{RMC} = \frac{1}{4}\mathbf{RMC}_{\mathbf{low}} + \frac{3}{4}\mathbf{RMC}_{\mathbf{high}} \qquad \text{Eq. 4}$$

Using this equation for RMC, the performance of the stainless steel prototype basket is 20% higher than the smooth plastic baseline basket. This meets project objectives and improves on the existing plastic ribbed basket product design.

3.3.12 Commercialization

The stainless steel prototype baskets work well for testing, but cannot be used for mass production. One of the primary requirements for a production basket is low cost. For a stainless basket, the cost is heavily dependent on material weight. A double basket design is inefficient in the use of materials and can be improved by replacing the outer hoop with smaller strap-type hoops.

3.4 Suds Lock

Suds lock is well known to appliance manufacturers. After the wash cycle, soap and soils are dissolved or suspended in the wash water. The basket begins to spin and water is extracted from the clothes and enters the annulus between the basket and tub. Normally, water drains to the bottom of the tub into the pump and is discharged from the machine. If the soap concentration is too high, foaming can occur.

If enough foam is produced so it fills most of the annulus, the basket rotation slows. A slower motor has lower back EMF that results in an increased current draw by the motor that can lead to overheating, and in worst cases, the motor overload circuit will trip, stopping the machine cycle prematurely. In machines with clutches in the drive train, the clutch surfaces can be appreciably scored or worn, degrading machine performance. Besides machine damage, suds lock causes the consumer considerable inconvenience as the condition requires multiple rinse cycles and manual operation of the machine to clear.

Recently, suds lock has become more common as clearances between baskets and tubs decrease to minimize water usage and as spin speeds increase. Pumps more resistant to clogging can also result in more suds lock complaints. Suds lock was investigated in this project to enable high-efficiency developments as the prototype ribbed basket showed increased susceptibility to suds lock.

3.4.1 Root Cause

Washing machine drain pumps are designed with large clearances between the impeller and housing to reduce clogging. While they work well in pumping clear water, aerated water reduces the efficiency of the pump drastically. Water entrained with air, as is the case with high soap concentrations, will slow the discharge from the machine and cause water to fill the tub under the spinning basket. When the water reaches the bottom of the basket, extreme shearing action takes place generating soap films and foam.

Once started, the production of foam increases. Quickly, the lower tub is filled with foam and the spinning action pumps this foam into the annulus between the basket and tub. As more work is put into the foam, the "bubbles" become smaller and the foam becomes stiffer, much like whipped cream. The foam is now capable of imparting significant drag on the basket.

Reducing the ramp-up rate when starting the spin is a well-known method for mitigating suds lock, but requires expensive variable-speed motor and drive systems. Most high-end washers, both VA and HA, use this method to control suds lock. This section investigates low cost methods to improve suds lock performance.

3.4.2 Influential Factors

Suds lock is a race between water extraction from the clothes and extraction from the tub bottom. A machine designer can limit the extraction rate from the clothing and basket or an attempt to "knockdown" the suds could be tried. Experiments were run to investigate these options.

Several configurations and control algorithms were investigated: number of basket holes, number of ribs, drain spin delay, and annulus spray. By limiting the number of basket holes, the water extraction rate from the basket should be reduced. This may have a negative impact on soil removal, especially larger particles such as sand.

The number of ribs in the machine changes suds lock performance. A higher number of ribs will increase the water extraction rate and decrease suds tolerance. Adding a delay after spin allows "drip dry" of the clothing, effectively decreasing the water extraction rate, but increasing the overall cycle time. A customer may view this algorithm poorly as the machine is sitting idle during the wash cycle. The annulus spray idea uses fresh water sprayed into the annulus in an attempt to clear suds from the region. An obvious drawback here is the higher usage of water.

The following table shows the suds index of various configurations. The desired performance is > 2.0, twice the manufacturer's suggested soap amount.

A main effects plot shows the big influences in suds lock: rib number and drain delay. The desired performance is a suds index > 2.0, twice the laundry product manufacturer's suggested amount.

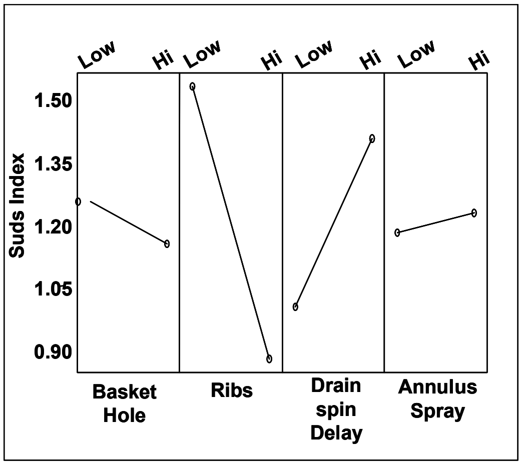


Figure 20: Suds Lock main effect plots

3.4.3 Solutions

PUMP

The obvious solution to suds lock is to improve the capability of the pump to move aerated wastewater. An efficient pump was mounted on the washer and achieved a suds index greater than 3.0.

Unfortunately, the machine designer is limited in options because clogging must be considered. All known methods to improving the pumping efficiency will bring clog performance down to unacceptable levels.

MAIN EFFECTS RECOMMENDATIONS

Reducing the number of ribs is contrary to the work of this project and adding a drain delay adds cycle time to the wash cycle. Both are not desirable solutions.

The annulus spray and hole modifications were ineffective in improving suds tolerance.

ALTERNATIVES

Alternative ideas were prototyped in the lab, though no clear winners were identified. The prototypes included sump covers that tried to direct the water into the pump; corkscrew channels in the tub to direct suds and water downward and various ramp rates for basket spin startup.

3.5 Suds Lock Summary

Unfortunately, a low-cost suds lock solution was not discovered. None of the prototypes resulted in clear improvements and most were difficult to envision in a production application. However, this research has emphasized the need to address the issue of suds lock and work in this area will continue with private funds.

4 Dryer Technology

Dryers are one of the highest electrical energy users in U.S. households. The drying time for a load of clothes can be up to twice as long as washing time, bottlenecking the laundry process.

This section reviews the work performed to improve the efficiency of the dryer and control techniques to better determine the true end of the drying cycle.

4.1 Drying Process

At startup, the drum starts turning and the heaters are turned on full power to bring the system and clothes load to temperature. The drying process can be described using the four stages of the Lyons-Vollers model as illustrated in Figure 21.

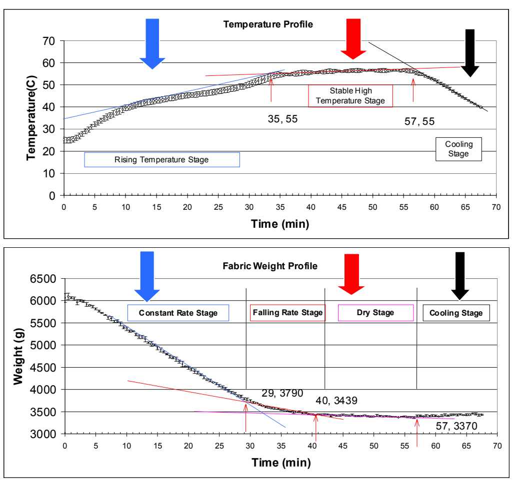


Figure 21: Drying Profiles

The falling rate stage presents the core difficulty in detecting when the cycle is complete. The RMC and most other process values are asymptotic to the steady-state value and have very low slopes. High sensitivity sensors are not currently available to detect this type of event.

Two areas of improvement are evident: improve the efficiency of the constant rate stage and improve end-of-cycle (EOC) detection to reduce energy usage in the drying stage.

4.2 Instrumentation and Testing

To investigate the various control techniques and energy savings, the climate control chamber at the GE Global Research Center was used. The chamber is capable of maintaining temperature and humidity levels representative of common installed usages.

Vent restrictions were simulated using several restriction plates from 1" to 3.75". Proper exhaust ducts were in place to ensure accurate restriction control and to prevent recirculation of exhaust air back to the heater inlets. Many sensors such as mass flow, temperature, pressure, and humidity were installed on the dryer to observe process variables. Existing appliance sensors such as moisture rods and thermistors were tapped to provide a signal for the DAQ system.

An xPC system was used to test algorithms and to collect data. The system allows Matlab Simulink code to execute in real-time with direct connections to the dryer sensors and actuators.

Variable speed drives and motors were installed to investigate the effects of changing drum rotation speed and blower speed algorithms.

4.3 Heater Controls

The first method investigated to improve dryer efficiency was that of heater controls. The baseline dryer is an automatic temperature control (ATC) dryer. The dryer has several thermostat switches that work in conjunction to turn on and off the heater coils. The exhaust temperature switch works in combination with the user dial timer to determine EOC based on a temperature rise.

During operation the heater switches between full power and half power by turning on 1 or 2 heating coils. Several control techniques were investigated to improve the rudimentary on-off control.

Case A reduced the heater power by about 5%. This caused the heater temperature to remain below the thermostat temperature so the heater would remain on a full power rather then cycle on/off as the baseline. Case B profiled the heater with a sinusoidal curve.

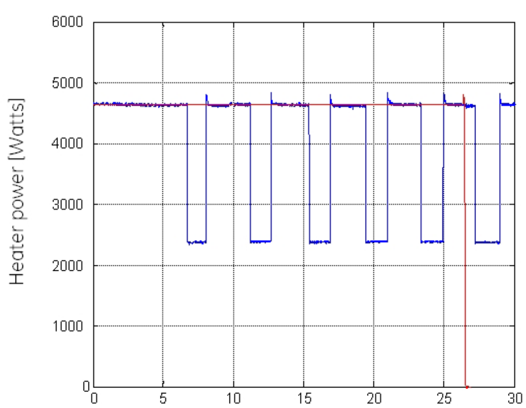
Case C added about 10% power to the heater and airflow was increased to maintain safe air temperatures. Case D used a constant heater power and controlled air temperature using a feedback loop to control blower speed.

Simulations were first performed to investigate potential benefits. Prototypes were also constructed to validate the modeling predictions for cases "C" and "D." The results are shown in Table 1.

		Baseline		Modified	
Exp	**Control**	**Time**	**Energy**	**Time**	**Energy**
A	Constant Current	34.2	1.98	-9.9%[1]	-0%
B	Sinusoidal Current	34.2	1.98	-6.1%[1]	-0%
C	Constant Current	34.2	1.98	-22%	-0%
D	Variable Blower	31.3	2.07	-15%	-0%

Table 1: Heater Control Results

Regardless of the control technique attempted, there was no impact on energy consumption. This conclusion is not entirely surprising as the heater supplies the work done to remove water from the clothing. The efficiency of the process has not changed, the alternate control techniques simply allow heater energy to be delivered uniformly throughout the cycle instead of cycling on and off.



[1] Results from simulation

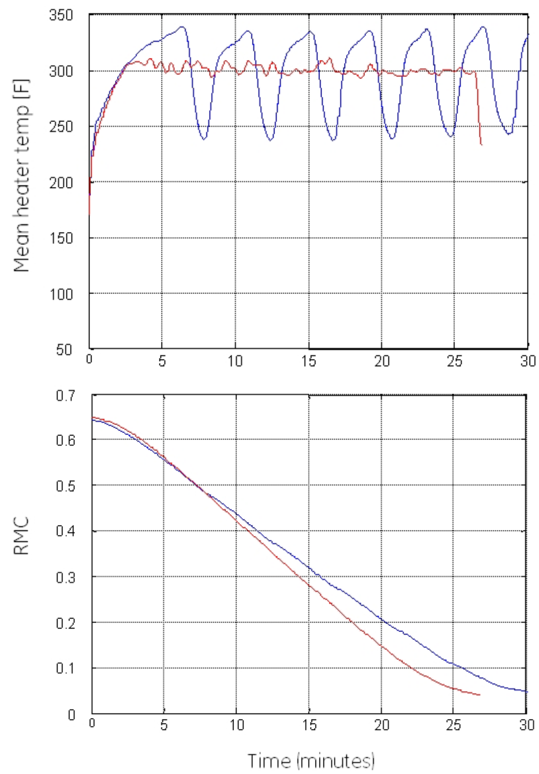


Figure 22: Variable Blower Control Technique

4.4 Drum Experiments

In addition to heater controls, occasionally reversing the drum rotation and changing the drum rotation speed was investigated.

Reversing the drum direction can reduce the "balling" of large items such as bed sheets. When a large item is tumbled in one direction, the item tends to wrap up into a tight ball, restricting airflow to the center. Reversing the direction can unwrap the item improving drying. In lab tests, however, DOE test cloths showed no improvements with reversing drums, primarily because the small size of the DOE test cloths makes them resistant to balling.

Changing the drum speed also showed no improvement. The tumble dryer has been through countless design reviews in its long history and the drum speed has been optimized well.

4.5 Overdrying

GE lab tests show that a typical automatic cycle dryer over-dries clothing considerably, in some cases, by over 100%. Besides excess energy usage, overdrying clothing appreciably shortens clothing life and contributes to shrinkage.

The overdrying time is defined by measuring the time when the load reaches an RMC of 4% until the dryer enters the cooldown cycle. During this time, the heaters are on and, because of the lack of moisture in the clothing, are simply raising the temperature of the cloth.

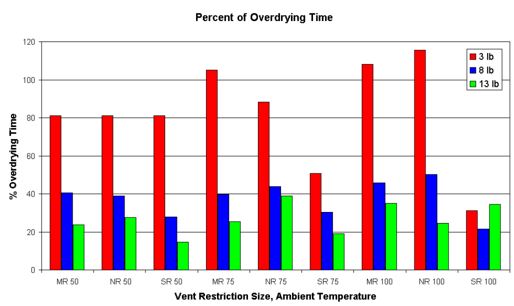


Figure 23: Overdry Performance

By reducing the overdry time, the customer is happy to see reduced dry times, while at the same time, saving energy. The challenge lies in better use of sensors and improved control of the dryer to better sense when the dry event occurs.

4.5.1 Sensors

MOISTURE RODS

Moisture rods are the state of the art for moisture detection in a dryer. Moisture rods are the current state of the art and work by measuring the conductivity of the clothing in the dryer drum. Clothing touches the rods and becomes part of an electronic circuit. Various techniques can be used to measure the conductivity, but each is generally valid only in the middle range of RMCs (15%-80%). Most importantly, at the low range of RMCs, the sensor looses sensitivity and an educated guess must be made when the load will finish drying based on the first segment of drying and user selections.

One manufacturer has incorporated slip rings into the dryer drum to realize the moisture rod functionality by using the drum and baffles of the drum as the conductors. This improves sensitivity by increasing the contact area between the sensor and the clothing. An adjustable gain control in the electronics also improves the sensitivity. Unfortunately, this system adds significant cost and reliability concerns to the appliance.

The voltage output of a moisture rod follows the RMC of the clothing, though not perfectly. A transfer function was developed to map rod sensor voltages to RMC.

One single transfer function cannot be used for all conditions because the function is dependent on the load size and other factors. The moisture rod behavior is also poor at the start of the drying process. Another limitation of the moisture rod sensor is the inability to measure low RMC values, where end of drying occurs.

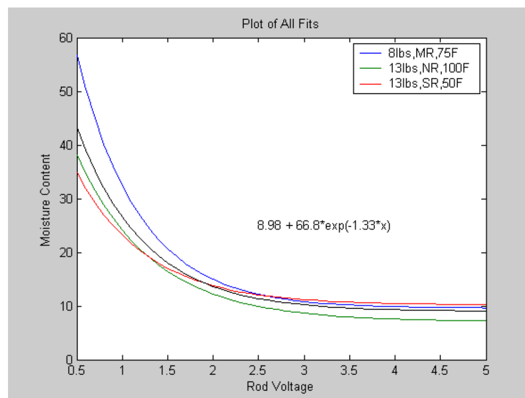


Figure 24: Moisture Rod Performance for Various Loads

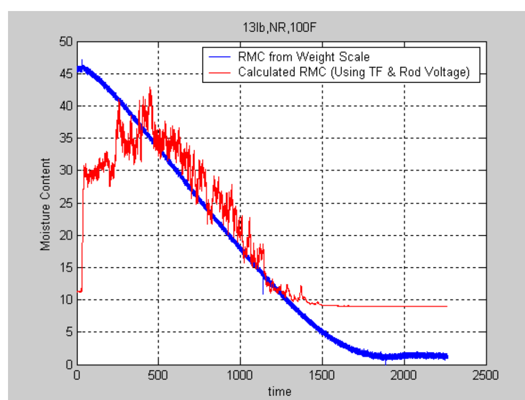


Figure 25: Moisture Rod TF Performance for 13lb Load

WEIGHT SCALE

The most accurate means for detecting the end of drying is by placing the dryer on a weight scale. By measuring the weight of the dryer and compensating for the buoyancy effect of the hot air in the drum, the RMC of the load can be accurately determined. The cost of a weight scale is prohibitive for commercialization, thus an alternative load sensing method is desired. In addition, the RMC calculation requires a priori knowledge to the dry cloth mass; a weight scale alone cannot determine the difference between a few wet items or many damp items.

PHASE ANGLE LOAD SENSING

Based on previously patented GE technology, a method for determining load weight was tested. The dryer drum that is in turn driven by a motor lifts the load. It is feasible to measure the torque on the motor to infer the load weight. Measuring the tension in the belt on the drive side could also provide a sensing point.

GE installed a phase angle sensor, developed prior to this project, to measure the load on the motor. The sensor outputs a signal that is proportional to the phase angle between the voltage and current waveforms. This phase angle is proportional to the load torque on the motor, a good indication of load weight. While the sensor operated well, the sensitivity of the measurement to noise parameters was great.

Tumble dryers use simple felt and plastic bearing surfaces that are highly susceptible to load variations. Application of the phase angle sensor was abandoned because the variation in friction was much greater than the variation in load at low RMC. A costly redesign of the dryer bearing surfaces and air sealing methods is required to move forward with this technology.

HUMIDITY SENSING

Relative humidity is a seemingly obvious sensing method to detect the EOC as the humidity level will drop as the clothing dries. There are several factors that limit the success of an RH sensor in the dryer environment: condensation, lint, and sensitivity.

Condensation occurs when the dryer starts and the RH sensor is cold. Hot, saturated air leaves the dryer drum and condenses on the sensor, permeating the sensor body with liquid. Typically, the RH sensor can recover from the water intrusion, but the time for recovery is often longer than the drying cycle itself.

Lint is generated by the washing action of the washer agitation. As the clothes dry, the lint separates from the clothing and is sucked through the exhaust duct. Coarse filters prevent most lint from getting to the duct, but blow-by and small lint particles will eventually collect on the RH sensor. Once coated in lint, the contamination attracts moisture from the hot air stream and creates a microclimate of high humidity. The time constant of the RH sensor is increased, making the frequency response of the sensor difficult to characterize.

Lastly, the RH of the exhaust air does not quickly transition from saturated to dry when the drying process is complete. The transition is gradual and difficult to assess. RH is not necessarily proportional to the RMC and, without a known relationship of RH to RMC, the end of drying can only be estimated.

Alone, the RH sensor can make only small improvements to EOC detection. However, there are substantial benefits when the sensor is used a part of a suite of sensors providing input for advanced controls that will be described in following sections.

4.5.2 Advanced Dryer Control

The approach taken here uses a model, primarily based in physics, to provide insight to process values not normally sensed, such as cloth temperature and evaporation rates. In conjunction with the model, additional control techniques can compensate for deviations of the model from the actual process. The expected result is a robust end of cycle detector that will greatly reduce the amount of overdrying.

MODELING TERMINOLOGY

The term "model" refers to the mathematical representation of a physical process. In this application, the model describes the relationships between the process variables and environment. The model does not, however, include the parameters, or characterization coefficients that are required to tailor the model to a specific appliance or operating point. These coefficients are determined experimentally.

HEATER MODEL

The model heater consists of energy balance equations and transfer functions that describe the gain and the time constant of the temperature dynamics. A portion of the energy is lost via conduction through surrounding structure and the remaining energy is used to heat up the air entering the drum via convention.

The primary purpose of the heater model is to provide estimates for air mass flow through the dryer. Because the vent restriction cannot be directly sensed, the airflow is an important process variable indicating restriction size.

DRYING PROCESS MODEL

The drying process model describes the temperatures and water content of air and clothes inside the drum, as a function of the conditions of the inlet air. The mathematical description is based on the macroscopic energy and mass balances for the air and water inside the drum, including the water evaporation process and moisture regain characteristics for specific clothes types.

Validation of the model is shown in Figure 26 for several operating points.

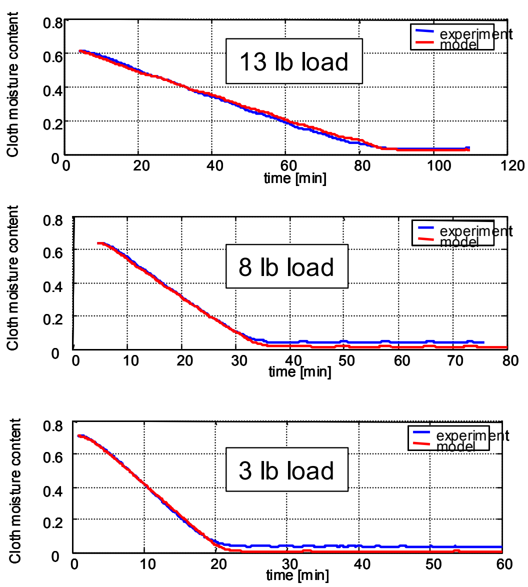


Figure 26: Model Validation

Although the model is based on first principles, and validates well, the parameters of such a model vary greatly across the operating range for the dryer. Significant effort was required to tabulate heat transfer coefficients for the model. These coefficients are highly dependent on the fabric type, load size, airflow, and moisture content. Second-order effects are drum material and ambient conditions.

Because of the volatility of the model coefficients, a technique for compensating deviations between the model and the dryer is required. For this purpose, an Extended Kalman Filter (EKF) was implemented.

EXTENDED KALMAN FILTER

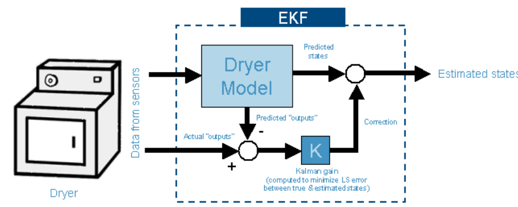


Figure 27: Extended Kalman Filter Implementation

An Extended Kalman Filter (EKF) is typically used to calculate an optimal estimate of a signal or parameter in a system. By using sensor data combined with the system model, the EKF can provide an optimal estimate for the actual process variables, which are distorted by noise as well as the other system states that are not being measured directly by a sensor. This is done by optimally blending the information from the sensors and the model to come up with a best estimate.

In this particular application, an example of a noisy sensor signal that is optimally estimated would be RMC, exhaust temperature and exhaust specific humidity. An example of signals not tied to sensors are mass of dry cloth, drum temperature, and cloth temperature.

The importance of the EKF in this application is for estimating the mass of dry clothes. This value can then be used, in the model, to predict when the process will reach the end of cycle. This method would extend the usefulness of the moisture rod sensors when sensitivity to RMC is lost near EOC.

EOC DETECTION ALGORITHMS

During the initial phases of drying, the EKF will determine the mass of dry clothes. Once the mass of dry clothes is known, the EKF is turned off and the dryer model is then used to predict the end of drying cycle.

Using simulations, the observability of mass of dry clothes by EKF was demonstrated, given that the appropriate sensor suite was utilized. For consistent convergence, a relative humidity sensor signal was required. In a laboratory test bench, the RH sensor can easily be installed, but raises cost and reliability concerns for production machines.

Fluent, a computational fluid dynamics vendor was subcontracted to investigate methods for locating a relative humidity sensor in the exhaust stream in a manner that would reduce lint accumulation. Discussion and results of this work are reported in Section 4.6.

4.5.3 Experimental Validation

A validation of the EKF simulations is needed to ascertain the sensitivity of the EKF and the model to uncontrollable and uncertain process events.

EOC DETECTION ALGORITHM TESTING

The EOC Detection algorithm was loaded into the xPC platform. During initial experiments, the variability of the heat transfer coefficients caused poor convergence of the mass of dry clothes estimation. However, several operating points performed well with regard to mass of dry cloth convergence. The impact for these cases to overdry time is shown in Table 2. The percentage values describe the proportion of the cycle that is overdry compared to the entire cycle time.

Load Size	**3 lb**	**8 lb**	**13 lb**
Restriction Size	**MR**	**MR**	**MR**
Ambient Temp	**50 °F**	**50 °F**	**75 °F**
Baseline	62 %	24 %	19 %
EKF Overdry Time	25 %	10 %	19 %
Entitlement	13 %	6 %	12 %

Table 2: EKF Overdrying Performance

Load Size	**3 lb**	**8 lb**	**13 lb**
Restriction Size	**MR**	**MR**	**MR**
Ambient Temp	**50 °F**	**50 °F**	**75 °F**
EKF Energy Savings	17%	8%	0%
Entitlement	24%	11%	4%

Table 3: EKF Energy Savings

Significant improvements can be made to energy savings and consumer satisfaction if the end of cycle can be detected more accurately. Though the current work is not mature enough to commercialize, it shows proof-of-concept for model-based control of the drying process. The next step to improving the performance is the development of next-generation sensors that supply data to the control algorithms.

Because of this project, GE's Global Research facility is now privately funding work on such a sensor. The sensor is expected to reduce the model's sensitivity to heat transfer coefficients by improving moisture measurements. Combining state of the art sensor technology and controls will enable the fast dry times, high quality clothes care and leading energy efficiency.

4.6 Humidity Sensors

Previously, the obstacles concerning the installation of an RH sensor were described. From the modeling discussion, it was emphasized that an RH sensor is needed to obtain the desired observability index needed to make the EKF algorithm reliable. This section describes efforts to overcome the conventional obstacles to RH usage.

Preventing condensation build-up on the RH sensor can be solved in two manners. First, the sensor can be heated to prevent condensation from forming. However, this can lead to temperature compensation errors and shortened life. The preferred method is to coat the sensor with a hydrophobic barrier that allows water vapor to pass while blocking liquid moisture. Any condensation cannot enter the body of the sensor and quickly evaporates from the surface of the sensor. Drains and other water management features can also be designed into the structure of the sensor.

Lint accumulation can be reduced by properly locating the sensor in the airstream and by tailoring the airstream for the sensor. GE utilized computational fluid dynamic analyses to design an exhaust feature the separates lint from the airstream. By placing the sensor in the proper location, lint accumulation is expected to be reduced significantly.

4.6.1 Model

Fluent was subcontracted to develop three-dimensional CFD models for predicting the flow of lint-laden air in the exhaust system of a dryer and the resulting separation of lint under various situations. The blower, housing, and exhaust plenum were modeled. A multi-phase flow was modeled to determine particle concentrations in the airflow.

CHARACTERIZATION

Lint is not a well-defined substance, though upper and lower bounds to particle size and densities can be determined. References such as Morton & Hearle[6] and Morrison, et al[7] characterized lint ranging in size from 1 micron to 100 microns and having a density of about 1 g/cm^3.

4.6.2 Results

Particle separation for the 90° bends was segregated between large and small particle sizes. For the 100-micron case, inertial effects dominate the particle path, nicely separating the lint from the airstream. In the one-micron case, though, the particles follow the airstream much more closely and act differently than the larger lint particles. In Figure 28, it looks like the lower portion of the outlet elbow would be a clean location for the sensor.

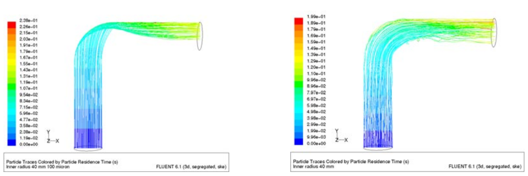


Figure 28: 100-micron (L) and 1-micron (R) particle flow. Analysis by Fluent

Figure 29 shows the particle concentration for 1 micron lint on the inside surface of the elbow. There is a high concentration right after the bend, making this unsuitable. From the elbow simulations, a clear location is not apparent.

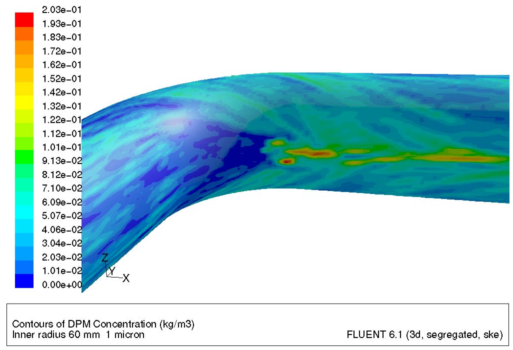


Figure 29: 1 micron particle concentration. Analysis by Fluent

BLOWER SIMULATIONS

Similar simulations were carried out for the blower and outlet assembly to investigate other opportunities for lint separation. Similar results to the straight elbow are observed, however, there is additional swirling generated from the blower and abrupt turn. The location on the inside of the elbow has similar properties to the 90° elbow in that large particles are separated well and small particles show higher concentrations.

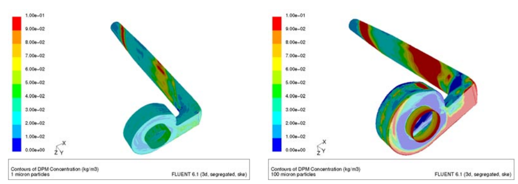


Figure 30: Concentrations, 1 micron (L), 100 micron (R). Analysis by Fluent

CONCLUSION

The computational analyses indicated the blower wheel imparts significant swirl to the exhaust air, which causes air to flow in a spiral circulating fashion in the exhaust duct. This airflow pattern, due to its centrifugal force, might be effective in drifting large lint particles towards the outer edge of the exhaust duct, but will likely not be capable to separate small lint particles effectively. In creating any natural lint-free zone for the sensor placement, an effective separation strategy for the separation of small particles needs to be developed either by employing and modifying the current swirling patterns in the exhaust duct or developing an in-line cyclone separator for separating the small particles.

4.7 Dryer Summary

There are two ways to reduce the energy usage of clothes dryers: increase efficiency and reduce overdry time. No efficiency benefits were obtained with new control algorithms. It is concluded the tumble dryer process is very near the entitlement for energy efficiency and drastic changes, such as utilization of microwave energy or otherwise, is needed for improvement. Overdry times were varied but significant, particularly at small and medium load sizes.

The development of the dryer model and EKF demonstrated the need for improved sensing capability in the dryer to make substantial improvements in EOC detection. General Electric is privately funding a sensing effort to address this need.

Relative humidity sensing also remains beyond the realm of commercialization. Elimination of small particle contamination requires considerable development before sensor reliabilities on the order of appliance life are achieved.

5 Chemistry

Researching laundry chemistry opens possibilities to the washer design and drying process that enable higher efficiencies to be obtained. GE Global Research has teamed with Procter & Gamble in Cincinnati, Ohio to develop new chemistry formulations to assist in water removal and reduction of drying time.

U.S. consumers utilize appliances (washers & dryers), laundry products (detergents & conditioners) and energy (gas & electricity) to satisfy their need for clean garments that look & feel good and wear longer. Cost and convenience are important factors in achieving their desired end-results.

Over the last 25 years, conservation of energy in the laundry process has been primarily focused on reduction of wash-water temperature. A broad range of cleaning and garment care technologies developed exclusively by Procter & Gamble has enabled temperature reductions by giving consumers products that meet their expectations. However, until now, P&G has not directed significant effort to developing product chemistry to accelerated drying. The opportunity to do so now is particularly attractive because it can be carried out in parallel with improvements in appliances to fully realize and leverage product-related benefits.

This effort offers a unique, integrated systems approach that includes both the washer and dryer plus enhancements to the drying process controlled by laundry product chemistry. In addition, the laundry chemistry can potentially be implemented easily on existing washer and dryer platforms, minimizing the time and investment necessary to make the new technologies available to consumers.

A new twist on improving the energy usage of the washing process is to investigate new chemistries and the interaction of these chemistries with the appliances. Procter and Gamble was chosen as a partner for their expertise and market leadership.

5.1 Current Appliances and Laundry Products

The first step in assessing chemistry benefits and performance was to understand the individual effects current appliances and laundry products have on the drying of fabrics.

5.1.1 Appliances

To conduct reliable and consumer relevant measurements, practical, sensitive and representative equipment are essential to our research. We have searched, selected and purchased dedicated laundry equipment for this purpose. Two washers and two dryers have been selected based on popularity of consumer sales.

Kenmore and Maytag appliances were chosen to complement the General Electric testing. The dryers were instrumented with RH, temperature and weight measurement and logging equipment.

5.1.2 DOE Test Cloth and Preconditioning

The standard DOE bundle is composed of 50/50 Cotton/Polyester, and is sourced from Textile Innovators. Preconditioning the fabric is necessary to stabilize the fabric for testing. Two preconditioning methods were compared: the standard DOE procedure and the standard P&G procedure.

The P&G procedure consists of 3 hot water wash / rinse cycles followed by 4 hot water rinse cycles and shows a slight improvement in stabilizing the cloth. Both methods were compared and they were found to be comparable and satisfactory. Although the P&G Method appears to stabilize the fabric a bit better, is believed the P&G method is more useful for finished garments.

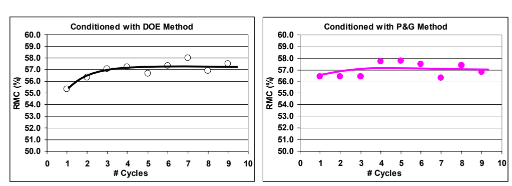


Figure 31: DOE vs. P&G Preconditioning

5.1.3 Consumer Fabric Load

In addition to investigating the DOE standard bundle, this 50/50 cotton and polyester blended fabric does not totally represent the consumer usage. Consumer data indicates that hard-to-dry items are often cotton, particularly with thicker weaves such as jeans and pants. Thus, P&G has made a representative load, shown in Table 4 composed of mainly cotton items that represent a typical consumer mixed load. P&G will use both the standard DOE bundle and the consumer bundle for research in this project.

Item	**Composition**	**Weight (g)**	**Weight (%)**
Hanes Beefy T-shirts	100% cotton	404	12%
Ultra Blend T-shirts	50/50 Polycot	1140	33%
Jean Pants	100% cotton	792	23%
Khaki Pants	100% cotton	569	16%
Pique Polo Shirts	100% cotton	290	8%
Terries	16/84 Polycotton	269	8%
Total	**82% cotton 18% polyester**	**3464**	**100%**

Table 4: Fabric Composition of Consumer Bundle

5.1.4 Laundry Products

In addition to investigating appliances' capability, the laundry market products are also benchmarked. Market products were selected and tested on both the standard DOE bundle and the P&G consumer bundle.

P&G MARKET PRODUCTS

P&G found that use of Tide liquid detergent in the wash reduces the RMC by 6% compared to water only treatment. It is theorized this decrease is attributable to lower of surface tension of water. It was also found that use of rinse-added Downy fabric conditioner following detergent wash further reduces the RMC, though only slightly. Results are shown in Table 5 and Figure 32. Figure 32includes range bars showing the variability between repetitions.

	Treatments (Wash / Rinse / Dryer)	**RMC After Rinse**
A	Control (H_2O/ H_2O/none)	75%
B	Tide Liquid / H_2O / none	68%
C	Tide Liquid / Downy / none	65%
D	Tide Liquid / H_2O / Bounce	67%
E	Tide Liquid / Downy / Bounce	68%

Table 5: RMC of Consumer Bundles with P&G Market Products

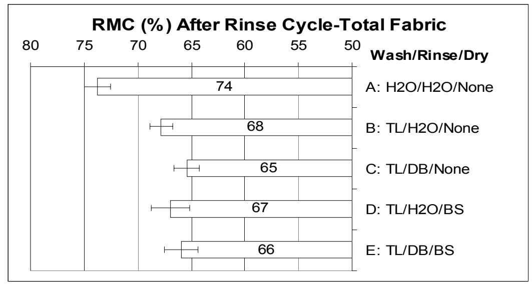


Figure 32: RMC of Consumer Bundles with P&G Market Products

DRYING TIME

The use of Tide liquid detergent in the wash can reduce the fabric drying time by about two minutes. This is attributable to RMC reduction achieved in the washer's spin cycle. The use of rinse-added Downy fabric conditioner following detergent wash further reduces the drying time slightly.

	Treatments (Wash / Rinse / Dryer)	**Drying Time (minutes)**
A	Control (H_2O/ H_2O/none)	35
B	Tide Liquid / H_2O / none	33
C	Tide Liquid / Downy / none	32
D	Tide Liquid / H_2O / Bounce	31
E	Tide Liquid / Downy / Bounce	31

Table 6: Drying Time with P&G Market Products

MARKET PRODUCT BENCHMARKS

P&G found Tide liquid detergent to achieve the greatest RMC reduction, and the detergents by competitors (Lever and Colgate) achieved smaller RMC reductions. Private label product (Sam's) is the least effective. The observed trend is believed to be a response to surfactant type and level used in the detergents.

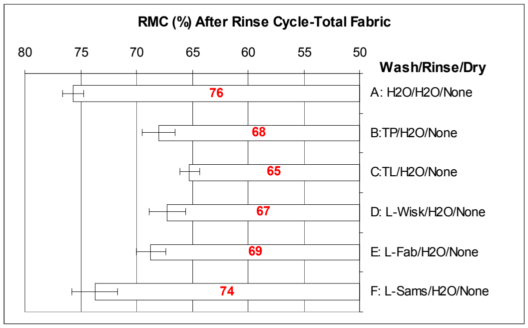


Figure 33: Drying Time with Market Products

The level of RMC reduction through use of detergent depends on fabric type. For example, the RMC reduction of Liquid Tide is about 11% for khaki pants, about 18% for cotton T-shirts, and about 28% for cotton terrycloth towels. The results from khaki pants and terry towels are shown in Figure 34 and Figure 35.

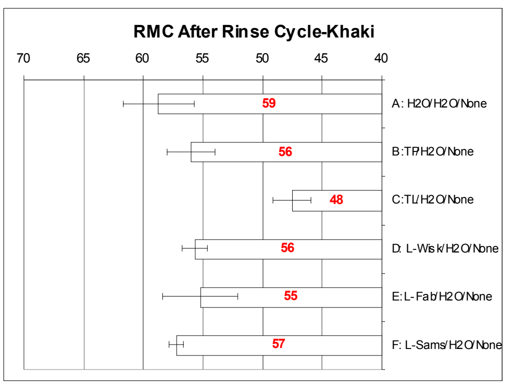


Figure 34: RMC of Khaki Pants with Market Detergents

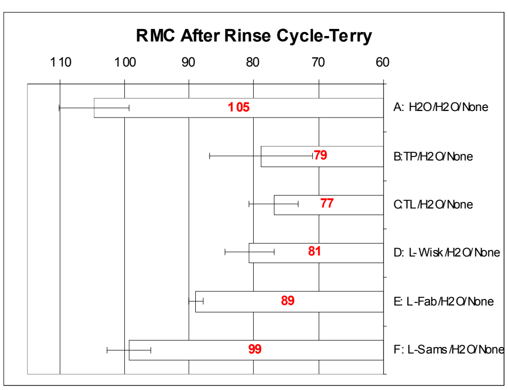


Figure 35: RMC of Terry Towels with Market Detergents

5.2 Screening Chemistries

Next, generic groups of chemistries and technologies that could affect the transport of water in fibers were investigated. The selected chemistry or technology will yield increased efficiency in the wash and or dry phases of the wash process.

P&G has evaluated major surfactant types: anionic, nonionic and cationic surfactants and silicone surfactants (superwetters).

5.2.1 RMC Reduction on DOE Bundle

Anionic surfactants (LAS & AES) and longer alkyl cationic surfactant (C16AlkylQuat) are slightly more effective than the nonic surfactant (Neodol). The most effective surfactants are silicone superwetters (Silwet L77 and SF 1488). Only fluoro-surfactants (not tested) are expected to be more effective than silicone surfactants.

Treatment		Type	RMC%	Relative Reduction
A	Water	Control	58	0%
B	LAS	Anionic in Powder	50	-14%
C	AES	Anionic in Liquid	51	-12%
D	Neodol 23-9	Nonionic	52	-10%
E	C12 AlkylQuat	Cationic	57	-2%
F	C16 AlkylQuat	Cationic	50	-14%
G	Silwet L-77	Silicone	45	-22%
H	SF 1488	Silicone	45	-22%

Table 7: RMC of DOE Bundle for Various Surfactants

RMC REDUCTION ON CONSUMER BUNDLE

Using the consumer bundle, the absolute RMC reduction is more pronounced. Consistent with the DOE bundle study, the silicone superwetters are the most effective, and reduce RMC by about 20% compared to the control. Other major surfactants achieve a 5-15% reduction in RMC.

This reduction in RMC is translated directly into reduced drying time. For example, Silwet L77 reduced the drying time by 22% compared to the control and 7% compared to LAS.

Treatment		Type	RMC%	Relative Reduction
A	Water	Control	80	0%
B	LAS	Anionic in Powder	65	-19%
C	AES	Anionic in Liquid	70	-12%
D	Neodol 23-9	Nonionic	66	-18%
E	C12 AlkylQuat	Cationic	69	-13%
F	Silwet L-77	Cationic	60	-25%

G	Silwet L-7607	Silicone	62	-23%
H	Silwet L-7608	Silicone	61	-24%

Table 8: RMC of Consumer Bundle for Surfactants

Treatment		Type	Time (min)	Relative Reduction
A	Water	Control	36	0%
B	LAS	Anionic in Powder	30	-17%
C	AES	Anionic in Liquid	31	-14%
D	Neodol 23-9	Nonionic	31	-14%
E	C12 AlkylQuat	Cationic	33	-8%
F	Silwet L-77	Cationic	28	-22%
G	Silwet L-7607	Silicone	30	-17%
H	Silwet L-7608	Silicone	30	-17%

Table 9: Drying Times for Consumer Bundle with Various Surfactants

The 22% reduction in RMC does not directly translate to dry-time savings. Approximately 5 minutes of dry time is saved for a 60-minute cycle compared to the improvement over Liquid Tide.

5.2.2 RMC Itemized Impact

Using a silicone super wetter leads to RMC reduction benefits across broad fabric types. The level of RMC reduction varies depending on the items, ranging from 9% to 39%. The Khaki pants were most improved and T-shirts and jeans least improved. The impact to the consumer hard-to-dry items is minimal, further decreasing the attractiveness of a silicone additive.

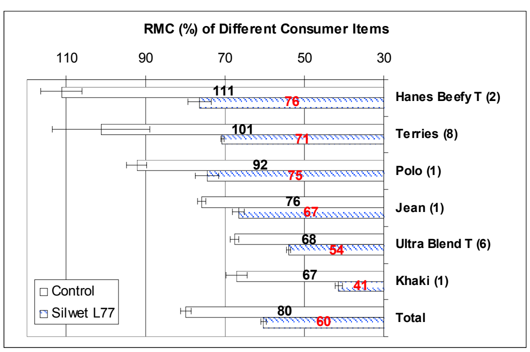


Figure 36: RMC Reduction with Silwet L-77

5.3 Dryer Chemistry

An alternative opportunity for improving the water extraction is to enhance the moisture transport from the clothing in the dryer. Three delivery methods were used: carryover from wash, fabric sheet, and dispenser. After the rinse and spin cycle of the wash process, some laundry product remains in the clothing. This carryover is a transparent method to deliver additive to the drying process. Many consumers use fabric sheets, so this is also considered a practical means to deliver an additive to the drying process.

Adding a dispenser to the appliance would require a major design change. In addition, the energy savings would be manufacturer-centric. Only machines with the dispenser design would be efficient and use of the technology in currently installed machines would be challenging.

P&G investigate several techniques to improve the efficiency of the drying process. Absorbing particles, similar to those in baby diapers, were added to wick moisture from the clothing and provide a larger surface area for evaporation.

Wetting agents were also added to encourage water to be released from the smallest capillaries allowing this moisture to evaporate, rather than boil from the clothing.

Some of these technologies showed modest improvement, but delivery methods were unsuccessful. Both the carryover and fabric sheet methods required such high concentrations of additive the cost would be prohibitive. Use of the dispenser, besides requiring major design changes, posed other issues in evenly applying the additive to the load. During tumble-drying, the load typically “locks” into a set orientation and rotates with the drum. Fabric on the interior may never come in contact with the dispensing means and high concentrations of additives can accumulate on the outside cloths.

Based on experimental testing, this method of reducing energy usage and dry times is not commercially feasible.

5.4 Suds Generation

The use of surfactants before the final spin in the washing machine will risk sudsing problems, including suds lock and residue on fabric. P&G has evaluated the sudsing tendency of various surfactants and has confirmed different surfactants have different level of risks. These results are shown in Figure 37.

Encouragingly, the most effective RMC reduction agents, silicone superwetters, such as Silwet L77, have the least sudsing. As a trade-off, however, silicone surfactants are expected to be much more expensive than conventional surfactants.

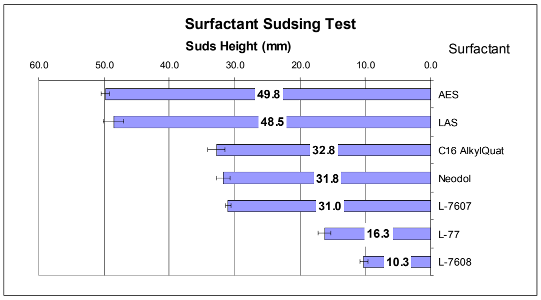


Figure 37: Suds Height

5.5 Chemistry Summary

Chemistry additives are available to improve energy efficiency of the laundry process when compared to the clear water baseline and in high concentrations in the dryer. A 24% reduction in RMC in the washer is not sufficiently commercially significant to initiate a new product development when compared to the existing laundry products that already reduce RMC by 10%.

The 14% reduction differential provides approximately 5 minutes of dry time reduction from 60 minutes for a full load, or about 8%. The added cost of the laundry product with silicone additives provides only a limited benefit that makes product differentiation and value difficult to achieve.

Additives operating in the dryer environment were found to be marginally effective only in very high concentrations. A dispersing method compatible with the laundry cycle is not possible.

6 Conclusion

With the rising prices of energy and continued move toward "green" appliances and conveniences, energy efficiency is a growing driver in today's economy. Though most consumers do not consider energy usage as a primary factor in appliance selection, other consumer desires are consistent with energy savings, specifically reduced process cycle time.

Reducing the RMC from the washer spin cycle improves the dry time of the drying process. Reducing the time over-drying the clothing in the drying process also meets the customer's goals.

This project has investigated many avenues to achieve energy efficiency in laundry appliances and two developments stand above all others as preferred means to meet energy standards: improved basket designs and model-based controls for automatic dryers.

Both solutions require further development and General Electric will combine results from this project and privately funded efforts to realize energy savings in future laundry systems.

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