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Technical background and design options to raise energy efficiency and reduce the environmental impact of domestic washing machines

Authors
Dr. Claus Barthel
Thomas Götz

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Index

1 Introduction and overview of design options

Many design options have been identified to increase energy efficiency and to reduce the environmental impact of washing machines

The environmental impact of washing machines is mainly caused by their electricity, water and detergent consumption during operation time. Because the worldwide development tends towards horizontal axis washing machines with the capability of compensating for the reduced energy consumption (especially due to lower washing temperatures) with more efficient mechanical work and extensive wash cycles in combination with high-efficient detergents, further design options usually refer to this type of machines. Several technical design options for increasing energy and water efficiency of washing machines already exist. Most of them are well known and their positive effect on electricity and water consumption is beyond question. While many of those technical design options have been implemented in most recent horizontal-axis washing machines, a systematic and worldwide approach to create a super-efficient appliance is still missing.

Cost is one reason. The purchase price of an extremely energy and water efficient washing machine can be too high to be offset by future electricity or water cost savings. Nevertheless, all energy and water saving design options - independent of costs - are presented here, as costs are relative and can possibly be lowered in the future through economies of scale.

The main measures to improve the energy and water efficiency of washing machines are targeting the following issues:

- Heating energy, depending on final temperature and suds level (amount of water used)
- Mechanical action, depending on running time and centrifugation
- Pumping (already fixed in most recent washing machines)
- Heat loss to metal drum, glass door, environment

2 Basic design options

The following table with focus on horizontal axis washing machines presents an overview of the most important technical design options for the European market (Reference: Options in WASH-2 and preparatory study, Faberi et al. 2007, p. 484-493) as well as estimations of savings and price effects.

Table 1: Technical design options in 2007 for the European market

Option	Description	Market application in the EU (2007)	Electricity savings		Water savings		Noise	Cycle time variation	Consumer price Increase (estimate)
		%	Wh/cycle	%	l/cycle	%	dBA	±min	€
1	Motor design	0.5 to 5	+50	+5	0	0	-2/3	-10	60 to 200
2	Time-temperature trade-off	100 (EU)	-	-	-	-	-	-	-
3	Mechanical action	20	+100	+10	2	+4	-6	-	90
4	Electronic controls	5 to 80	10 to 165	+1 to 17	5 to 11	+10 to 11	-5	-	1.5 to 87
5	Thermal efficiency	100 (EU)	-	-	-	-	-	-	-
6	Tub-drum geometry	100 (EU)	-	-	-	-	-	-	-
7	Rinsing optimisation	20	-	-	7.5	+15	-	-15	15
8	Increased loads	30	-80	-8	-3	-6	-	+15	0.3

Source: Faberi et al. 2007

The European Commission executed a Least Life Cycle Cost analysis of the different design options in order to evaluate, which of the options are economically most efficient. It was examined whether implementing a certain design option induces an increase in the net present value of the machine (discounted with interest rates). The following table presents the results, which are based on the assumption of a typical 15-year lifetime of a washing machine with 280 wash cycles per year and an electricity price of 17 ct/kWh. The most important design options are listed with corresponding data for simple payback time (SPB; an economic measure for the riskiness of an investment) and net present value (NPV; an economic measure for the attractiveness of an investment) calculated for certain conditions. The real-world value will depend on parameters such as the actual electricity and water price, the size of an appliance, and the cost of components (Faberi et al. 2007).

Table 2: Economy of technical design options in 2007 for the European market

	Description	Simple payback time / SPB (years)	Net present value / NPV (€)
Option 1	Motor design	32 to 130	-40 to -180
Option 2	Time-temperature trade-off	-	-
Option 3	Mechanical action	0.3	54.2
Option 4	Electronic controls	0.3 to 1.3	40 to 83
Option 5	Thermal efficiency	-	-
Option 6	Tub-drum geometry	-	-
Option 7	Rinsing optimisation	2.5	48.4
Option 8	Increased loads	-	-56.7

Source: Faberi et al. 2007

Design options which provide a positive NPV (= saving potential) over the lifetime of a machine are remunerative both from a producer's and a consumer's point of view. The analysis performed on behalf of the European Commission suggests the best design options with focus on the European Market and the dominating horizontal axis technology (Faberi et al. 2007):

1. Mechanical action optimisation (NPV: €54.20)
2. Electronic temperature control sensors and simple unbalance control (NPV: €43.26)
3. Analogue water sensor (NPV: €40.72)
4. Rinsing phase optimisation (NPV: €48.37)
5. Optimised motor composition (NPV: €3.00)

However, in other world regions, the adoption of other options may be reasonable as well. For example, where saving potentials are not realised yet, it may be best to optimise e.g. the time-temperature trade-off, thermal efficiency or tub-drum geometry first (Faberi et al. 2007).

2.1 Motor design

Using brushless DC motors or three-phase motors may increase motor efficiency by 6 % compared to less efficient AC motors. This implies possible savings of 30 to 50 Wh per rinse cycle. If the motor is directly mounted to the axis of the washing drum, noise and vibrations due to the traditional belt-design may be reduced. For variable-speed motors, the optimisation of electronics and controls (see 2.4) is necessary.

Additionally, the motor design can be optimised with respect to materials used. 5 % less materials (copper, iron) may be used. This does not affect motor efficiency, but resource consumption (Faberi et al. 2007, p. 488).

2.2 Time-temperature trade-off

A trade-off between washing temperature and the total duration of a wash cycle exists (i.e. decreasing the temperature will lead to longer wash cycles). However, this option is considered as already being exploited as far as possible in the EU (Stiftung Warentest 2011). It might, nevertheless, be an option yet to be exploited for some low-cost appliances in non-regulated markets (Faberi et al. 2007).

2.3 Mechanical action

In 1998, the application of complex mechanical action as well as spinning during the wetting phase was considered to lead to a reduction of suds volume by 2-3 l and to savings of 100 to 50 Wh per cycle (due to reduced heating). In 2005, the European Commission specifically considered the use of advanced motors as a good option to further improve the mechanical action (Faberi et al. 2007).

2.4 Electronics and controls

2.4.1 Unbalance control for drum load

In 2005, 90 % of all washing machines in the EU were expected to contain at least some sort of simple mechanical (frictional or high-pressure) shock absorbers. More sophisticated absorbers, capable of detecting an unbalance of the load, were applied to 5 % of marketed machines (Faberi et al. 2007).

2.4.2 Load, Water and Temperature Sensors

Over 90 % of washing machines in the EU had at least partial electronic control in 2005. Sensors can measure the load weight, the water level and temperature. This information provides the base for further electronic controls such as calculation of optimal water and detergent quantity use, prevention of overheating and choice of optimal mechanical action (e.g. by variable speed motors). With more sophisticated electronic controls installed, the machine can apply ‘fuzzy’ logic to determine optimized parameters for the washing programme (Faberi et al. 2007).

2.4.2.1 Temperature sensors

In 1998, electronic thermostats were considered as being too expensive to be used in an optimal design, whereas in 2007 over 80 % of marketed European machines included this technology (Faberi et al. 2007).

2.4.2.2 Effective Load Sensor

Overall, it is most important that the size of a washing machine is correctly dimensioned with regard to the actual needs of a household. Due to the general market trend towards larger washing machines (capacity of 6 to 10 kg per cycle) and frequently unchanged traditional wash habits, washing machines in many households are too often only partially filled.

Considering this development, it is even more important that washing machines also have a sensor capable of estimating the weight of the laundry load and which is able to automatically adjust programme duration, energy and water consumption accordingly. A half loaded machine would theoretically lead to a reduction of 50 % of electricity and water consumption compared to a full load. Under real-world conditions, a reduction of about 15 to 20 % can be achieved through load sensors. Load control features should be accompanied by an eye-catching visual indication in case of failure, to prevent full-load setting as default for long periods (Josephy et al. 2011).

2.5 Thermal efficiency

In Europe, total energy consumption for machine-heat up and convection losses has been reduced from 276 Wh/cycle in 1993 to 175 Wh/cycle in 1998. By 2005 the European Commission had not seen any further potential for improvement (Faberi et al. 2007).

2.6 Tub-drum geometry

In 2005, there were no apparent further enhancing options for the European market with regard to the tub-drum geometry (Faberi et al. 2007).

2.7 Rinsing and spinning optimisation

Rinsing and spinning optimisation refers to the trade-off between minimising the amount of detergent remaining in the washed laundry (sufficient rinsing) and the use of water. A study in 1998 proposed the usage of only 3 rinses per wash cycle in combination with increased spinning action in order to achieve further water savings. By 2005 there were still optimisations possible, e.g. optimising spinning speed and water flows (Faberi et al. 2007). Therefore, a future EU standard, allowing the measurement of rinsing performance, is currently under development (Josephy et al. 2011).

A higher spin speed is one of the most important basic features to improve the efficiency of washing machines. A faster spin cycle extracts more water from clothing, saves drying energy for clothes or reduces time for air-drying. For example, in the US, clothes dryer energy use accounts for 44 % of total energy use for the laundering of clothes with conventional machines. Generally, a lower amount of remaining moisture in the washed laundry also makes air-drying a more attractive and feasible option (toptenusa.org 2011).

2.8 Increased amount of load

Increasing the load capacity within an otherwise identical machine allows for a higher energy efficiency class. This option may be viable especially for bigger households, commercial purposes or for reducing the number of wash cycles per week. In Europe this would mean an upsizing from about 5 kg to 6 - 10 kg machines (horizontal axis), in the US a slight downsizing (with regard to the traditional vertical axis machines) for efficiency purposes (Faberi et al. 2007).

Nevertheless, it is still most important that the size of a washing machine is correctly dimensioned in view of the actual needs of a household, because a partially loaded machine fitted with effective load sensors can only save 15 to 20% at best. A high-capacity washing machine that is typically under-loaded, could even intensify the energy consumption. For example, the comparison of 5 kg- vs. 7 kg-machines performed by the German Öko-Institut (2005) shows: In the case that consumers stay with their traditional use patterns in terms of same absolute loading, the acquisition and usage of a large washing machine results in higher environmental impacts as well as higher costs.

3 Further design options (Short-term)

3.1 Low-temperature and 'cold wash'

The major share of the electricity consumption by washing machines is required for heating water from tap temperature up to 30, 40, 60 or even 90°C. Washing at lower water temperatures (max. 20°C) requires up to 70% less electric energy compared to washing at 60°C. Since 2009, environment-friendly high efficiency detergents designed for low water temperatures are broadly available. These detergents became a quasi-standard for producers in Europe within a very short time and are recognised as an important innovation by the whole laundry industry sector. According to the recent European Eco-design regulation for washing machines, by the end of 2013 all new washing machines have to offer a cold wash programme with a maximum temperature of 20°C for cotton (Josephy et al. 2011).

3.2 Hot Water Supply/Hot-fill

Hot water supply ('hot fill') for washing machines can be both economically and ecologically reasonable, provided that the domestic hot water is heated efficiently, e.g. by renewable energy sources or district heating and that the proper installation of a warm water system is possible. The higher the commonly used washing temperature, the higher the potential savings from hot water supply (up to 70 % less energy consumption by the washing machine). The technology is available on the European market, but its actual use strongly differs within countries (Josephy et al. 2011). An alternative for machines without a hot water inlet (especially horizontal-axis machines) is an external add-on device, which mixes hot and cold water according to the requirements of the chosen washing programme.

3.3 Use of rainwater

The use of rainwater in washing machines can be a cost effective option to reduce the usage of potable water. Depending on local water and sewage water tariffs and the water consumption of the washing machines, the water costs for washing machines may be as much as 50 to 100 % of the respective electricity costs (Josephy et al. 2011).

3.4 Automatic detergent dispensing

The common practice by users to over-dose detergents can be prevented by automatic dosage systems. Correct dosage of detergents increases the rinsing quality and therefore reduces the amount of water required and the energy as well as the impact of chemicals released to the environment (Rüdenauer/Gensch 2008, Josephy et al. 2011).
Automatic detergent dispensing is especially applicable for liquid detergents in combination with the sophisticated sensor-controlled contemporary horizontal-axis machine technology. Up to now, however, predominantly premium sector washing machines include an automatic detergent dispensing system.

3.5 Steam

Steam cleaning technology is already in production and a feature in some premium-class horizontal axis washing machines. Steam can be used to heat and moisturise the laundry for a short refresh wash cycle or for washing with improved performance. In theory, this could further reduce the amount of water used in conventional horizontal axis washing machines and thereby the energy consumption. Manufacturers claim this technology uses on average 35 % less water and 21 % less energy than washing machines with energy efficiency class 'A' (related to the valid European energy class until end of 2011) and is also able to sanitize the laundry. However, as long as steam cleaning technology is only available within premium class products, it will only have a small market share (Defra 2009).

3.6 Silver ions, Nano silver

Washing machines equipped with so-called 'silver-ion' or 'nano silver' technology are already available from a few manufacturers worldwide. Silver is a useful disinfectant to inhibit bacterial and fungal growth, which can occur for example in washing machines that are not operated frequently or only at very low temperatures combined with insufficient detergents. Silver ions or silver nanoparticles can be introduced to the washing liquids by electrolysis using a silver electrode and are supposed to help remove bacteria in the laundry as well as in the washing machine itself (AEA 2009 / Defra 2009). By this means, significant energy savings could be achieved by providing hygienically clean laundry even at the lowest possible washing temperature ('cold wash' if available).

On the other hand, discharging nanoscale silver with the washing water may pose risks for health, impair the biological purification process of wastewater and negatively affect ecosystems. The reason is a differing and mostly unknown (to date) toxicological impact by nano silver, which does not arise from the traditional usage of metallic silver. Although there are not necessarily any genuine nano-silver particles used (some manufacturers claim that "nanotechnologies are involved in effective generation of the silver ions"), it is important not to dismiss the potential risks of this technology (AEA 2009 / Defra 2009). In terms of environmental impact they also add to the total amount of silver already discharged to the environment (Luoma 2008). Hence, the German Federal Institute for Risk Assessment (BfR 2011) generally warns of the use of nanoscale silver in consumer goods, for example.

3.7 Conclusion

With regard to existing technology, an improved spin-drying efficiency, the availability of low-temperature or cold wash programmes as well as the possibility to use an efficient external hot water supply offer the most relevant energy saving potentials (Josephy et al. 2011).

4 Future design options (Mid- to long-term)

Although the energy efficiency of washing machines can still be optimised, the further technical development of traditional water and detergent based clothes washing appliances is relatively limited in the near future and further savings are much more dependent on user-behaviour (Josephy et al. 2011). Nevertheless, further mid- to long-term energy and water savings could be achieved by a principle change of the entire washing or cleaning process. Some potential new technologies have been investigated by the UK Department for Environment, Food and Rural Affairs (Defra) and AEA (2009) in a preliminary report on reducing the environmental impacts of cleaning clothes.

4.1 Polymer pellets

A polymer-based washing system is currently under development at Xeros (xerosltd.com), a University of Leeds based organisation in co-operation with the washing and dry-cleaning industry. The washing process is based on the use of plastic granules (or chips), which are tumbled with the moisturised clothes and a detergent to remove stains. The soiling in the textiles transfers to the polymer beads, which are then removed. Periodically the beads need to be passed through a regeneration process but can be reused up to 500 times. The process appears to be effective for the full range of dirt, stains and fabrics that are commonly treated in conventional washing machines (Defra 2009). The technology is specified as using as little as a cup of water in each wash cycle (AEA 2009).

However, t has to be borne in mind that the Xeros pellet system represents a fundamental system change by replacing most of the water used in clothes washing with polymer chips and is therefore not compatible with conventional washing machine technology. Hence, completely new designs or strong modifications in existing designs will be needed before the polymer bead system can be introduced. But then however, according to the developers, the energy consumption could be reduced by 50 % and the water consumption by 90 %, compared to the most recently produced water-based washing machines. Furthermore, the laundry is claimed to be 'damp' rather than 'wet' at the end of the washing cycle, which could potentially further reduce the energy requirements for drying the laundry in a tumble-dryer (Defra 2009).

The technology could be used in domestic washing machines as well as in commercial washing machines. At the current state of research however, it is more likely that such an application will first be found as a commercial washing machine rather than as a domestic type (AEA 2009).

4.2 Ozone

Ozone technology based washing machines are currently available as a bolt-on for commercial laundries. Ozone can be generated by electrical sparking in air or by use of an ultraviolet lamp. It can be used as a supplementary bleaching and sanitizing agent at lower temperatures and therefore it has a potential for energy and water savings. Nevertheless, a certain degree of heating might still be necessary to achieve further cleaning functions by the detergents.

Furthermore, garments could be treated even without wetting them just to remove odours and bacteria. Additionally, the final rinse water from the washing machine could be sanitized so that it could be stored and re-used for the next wash or as coolant for the condenser in washer dryers.

Drawbacks to the ozone technology are a certain risk of chemically damaging textiles as well as the additional costs for generating the ozone. Due to a number of practical and technical problems, the adoption in domestic appliances is only a mid- to long-term option (Defra 2009).

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Dr. Stefan Thomas • bigee@wupperinst.org

Wuppertal Institute for Climate, Environment and Energy • Doeppersberg 19 • 42103 Wuppertal • Germany • Phone: +49 (0)202 2492-129