The Impact of Limescale on Home Appliances in a Building

Hajji Abdelghani[1], Abbou Ahmed[1] and El Boukili Abdellah[2]
[1] *Mohammedia School of Engineering, EMI, Ibn Sina Avenue,Mohamed V University, Agdal, Rabat, Morocco*
[2] *Higher Education School, ENS, Mohamed V University, P4014, Takadoum, Rabat, Morocco*

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Abstract: The problem of limescale in hydraulic devices that produce or use hot water is a well-known phenomenon in everyday life. It is common in the following appliances: electric water heater, washing machine, dishwasher, coffee maker, electric kettle, etc.
To overcome this problem, several approaches exist and can be applied to the different levels of the hot water production system.
This work enables to characterize the drinking water of some regions in Morocco, looks for conditions that minimize limescale production and shows experimentally that this latter has a significant effect on the energy bill of a building.
The results show that it is preferable to introduce a water filtering system (softener), especially in areas where water is hard or very hard. This will be applied to the building's water supply to reduce the energy bill, extend the life of hydraulic installations, reduce the frequency of maintenance, make soap and detergents more efficient and also improve the quality of drinking water.

1. INTRODUCTION

The energy efficiency of the building is a hot topic. In Morocco, a lot of researchers are interested in this topic because the building is the biggest energy consumer, before the transport and the industry. It also represents 25% of national carbon dioxide emissions. [Abarkan, 2014]

It is considered today as the fourth energy after fossil fuels, renewable energies and nuclear energy. The ambition of the Kingdom of Morocco is to ensure a better use of energy in all areas of economic and social activity, considering the need to rationalize and improve the consumption of energy to meet the growing energy needs of our country. [Law 47-09 on Energy efficiency 2015]

Buying economical household appliances is not sufficient since much of the electrical consumption of a piece of equipment depends on how it is used and how it is maintained throughout its life. [ADEREE, (n.d.)]

The phenomenon of limescale formation occurs in cold water urban distribution systems and more intensively in the heat transport circuits of industrial plants and in hydraulic devices that produce or use hot water.

The technological and economic consequences of scaling are varied:

- Loss of efficiency due to the insulating power of limescale, which increases the energy consumption (10 mm of limestone on the electrical resistance can increase losses up to 50%). [ASPEC SERVIGAZ, (n.d.)]
- Shortening of the life length of the already expensive equipment.
- Rise in the temperature of the appliances with the risk of destruction by overheating.
- The malfunction of the hydraulic devices.
- A progressive reduction of the pipes sections with an increase of pressure losses or even their obstruction.

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- In addition, tartar in large quantities is an agent promoting the development of certain bacteria such as Legionella. [Hadfi A., 2012]

Our research work, conducted by the Mohammedia School of Engineering (Mohamed V University of Rabat), begins with the measurement of the hardness of drinking water in 4 regions in Morocco. Then we will try to find, theoretically, the conditions that minimize the quantity of limescale in hot water taking into account the comfort and health of the occupants of the building.

Subsequently, we will show, experimentally, that drinking water which contains the higher quantity of limescale (higher TH) will require more energy to heat.

Finally, we will lead a comparative study about the energy consumption of the various hydraulic devices of a building using different waters.

2. RELATED WORK

There are very few published research data on the energy impact of limestone on home appliances.

Lerato Lethea (2017) has studied the impact of water hardness on the energy consumption of geyser heating elements. That study proved that the scale formation of 1.5 kW and 3 kW geyser heating elements because of high total water hardness rised the energy consumption by about 4% to 12%. It proposed an energy efficient electronic descaling technology. In my opinion, it is a good thing but it is necessary to act before the scale is left in large quantities. We suggest, therefore a softener which slows down scaling.

On the other hand, Konstadinos Abeliotis (2015) studied the impact of water hardness on consumers' perception of laundry in five European countries.

He showed that the hardness of water is a key factor in the success of the washing process project. For the first time, a research was conducted in five European countries aimed at identifying consumers' perceptions about the effect of water hardness in washing performances. In terms of water hardness, the respondents seem to be well aware that the areas in which they live, face problems due to the hardness of water. The results also indicate that satisfaction with the washing result, although related to high levels, depends on the hardness of water.

In the same study, we observe that the use of softened drinking water in households has several positive effects, such as the reduction in energy consumption.

In the same context, Bruce A. Cameron (2011) worked on consumers' detergent considerations: hard water laundering - How much additional detergent is needed?

He showed that liquid detergents wash in both fresh and hard water. Powdered detergents were more efficient than liquids in fresh water. The hardness of water affected powdered detergents and, depending on the type of detergent, 10-15% to over 30% additional detergent was needed to achieve a similar result to that of fresh water.

The last two studies got interested in the effect of water hardness in the washing machine and they tried to study the effect of all appliances in a building that use hot water.

3. WATER HARDNESS MEASUREMENT

We will begin this work by measuring experimentally the hardness of drinking water in four regions of Morocco. The hardness, called the hydrotimetric title (TH), corresponds to the totality of the calcium and magnesium salts:

$$TH = [Ca^{2+}] + [Mg^{2+}] \quad (1)$$

3.1. Equipment

The equipment that has been used in this study is the material that allows the experimental determination of the TH hardness of water:
drop sensor - LabQuest interface – eriochrome black T (NET) - tetraacetic ethylene diamine (EDTA) - buffer solution 5 ml (milliliter) - erlenmeyer 250 ml - magnetic stirrer and stir bar.

3.2. Method

The method to determine the total hardness of water is based on complexation assays to form very stable complexes between a central ion (Calcium, Magnesium) and an EDTA ligand.

In a 250-millilitre-Erlenmeyer flask, V_{water}= 50 ml of drinking water to be analyzed is added. 5 ml of the buffer solution and one drop of the NET indicator are added and then, the mixture is titrated with EDTA solution. The shift is reached when we get the royal blue color.

The equivalence relation is written as:

$$[EDTA].V_{eq} = ([Ca^{2+}] + [Mg^{2+}]).V_{water} \quad (2)$$

V_{eq}: Volume of equivalence

It is shown that the TH in French degree unit, noted ° F, is written as:

$$TH = 5.0,8.V_{eq}\,(ml) \quad (3)$$

3.3. Results

Here are the results obtained for the samples from 4 regions in Morocco:

Table 1: TH values of 4 regions in Morocco.

Water sample	E1	E2	E3	E4
TH in F °	41,60	28,48	28,00	10,24
Nature of water	very hard	hard	Hard	soft

3.4. Discussion

Depending on where you live and on the soil geology of your area, the water coming out of your faucet can be more or less hard. This is why it is important to be well-informed on this subject, otherwise you will deal with a lot of inconveniences caused by the limescale at home. [Union française des professionnels du traitement de l'eau, (n.d.)]

Limescale is naturally present in water. Its presence in small or large quantities depends on the nature of the terrain crossed.

In table 1, it can be seen that water E1 is the hardest one. It contains the higher quantity of limescale compared to the waters of the other regions. And water E4 is the softest one.

Hard water causes scaling of distribution networks and soap excessive consumption; fresh water can cause pipes' corrosion. So, water hardness should be moderated to ensure an acceptable balance between corrosion and scaling. [Sante Canada, 1979]

4. STUDY OF THE EFFECT OF TEMPERATURE AND PH ON LIMESCALE FORMATION

We will study, theoretically, limescale dissolution according to the following parameters: temperature T and pH.

4.1. Material

In this study we will use the Matlab software.

4.2. Method

To study limescale dissolution at temperature T and pressure p, it is assumed that:

- Limescale is assimilated to calcium carbonate $CaCO_3(s)$.
- The liquid phase is in equilibrium with the gas phase with respect to carbon dioxide exchanges.
- The ions activities are almost equal to the ions molar concentrations. [Cortial, N, (n.d.)]

The following reactions come into play:

$CaCO_3(s) = Ca^{2+} + CO_3^{2-}$ (K_S: solubility product)

$CO_2 + 2H_2O = HCO^- + H_3O^+$ (K_{a1}:acidity constant 1)

$HCO^- + H_2O = CO_3^{2-} + H_3O^+$ (K_{a2}: acidity constant 2)

The solubility S of calcium carbonate is defined by [Cortial, N, (n.d.)]:

$$S=[CO_2]+[HCO^-]+[CO_3^{2-}] \quad (4)$$

We can show that:

$$S=(10^{X-2.pH} + 10^{Y-pH}+10^{-Z})^{0.5} \quad (5)$$

With: $X = pK_{a1} + pK_{a2} - pK_S$

$Y = pK_{a2} - pK_S$

$Z = pK_S$

4.3. Results

Here are the numerical values of the parameters for different temperatures [Cortial, N, (n.d.)]:

Table 2: Values of parameters.

T(°C)	pK_{a1}	pK_{a2}	pK_s	X	Y	Z
0	6,583	10,63	8,022	9,191	2,608	8,022
25	6,368	10,33	8,341	8,357	1,989	8,341
50	6,296	10,17	8,625	7,841	1,545	8,625
75	6,186	9,99	8,862	7,314	1,128	8,862

Here is the representation of the solubility as a function of pH for different temperatures under the Matlab environment:

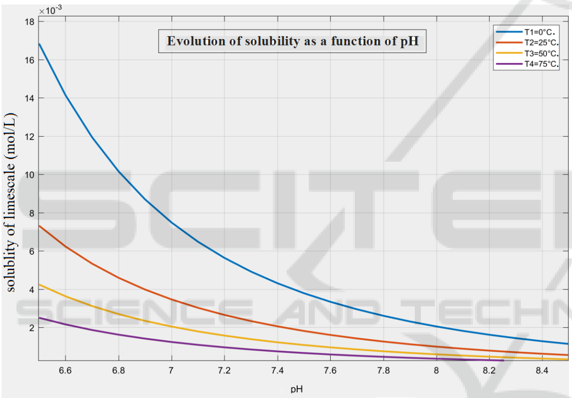

Figure 1: Solubility of limescale as a function of pH for different temperatures.

4.4. Discussion

Temperature has a significant influence on the solubility of calcium carbonate. The latter increases the presence of carbon dioxide. Indeed the increase in temperature decreases the amount of dissolved carbon dioxide and causes the precipitation of calcium carbonate. [Hadfi A., 2012]

From figure 1, we notice that the pH rise favors the formation of limescale. And the increase in temperature favors the precipitation of calcium carbonate. To minimize the quantity of the formed limescale and ensure comfort to the occupants, you should thus adjust your appliances to moderated temperatures between 55 and 60 ° C and the water pH should be between 6,5 and 7. [Health misitry, 2006]

5. EVOLUTION OF THE ENERGY SUPPLIED TO WATER ACCORDING TO TEMPERATURE

We will study the evolution of the energy supplied to water as a function of temperature for different TH values.

5.1. Equipements

Here is the material that makes this study possible: calorimeter - temperature sensor - LabQuest chain acquisition - computer - resistor 3Ω - 4 drinking water samples - graduated cylinder - 6V voltage generator - multimeter - magnetic stirrer and stir bar - connection wires.

5.2. Method

Here is the experimental setup:

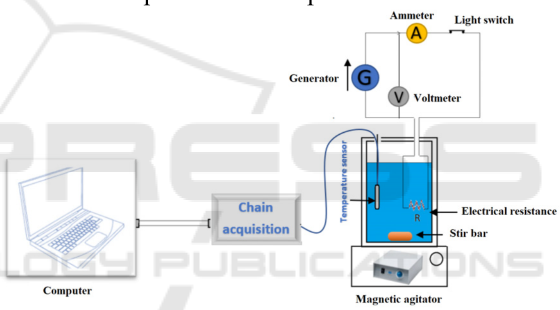

Figure 2: Experimental device.

The energy supplied to the water is calculated using the following relation:

$$E = R.I^2.\Delta t \qquad (6)$$

R: electrical resistance
I: current intensity (A)
Δt: required duration

We redo the experiment for the other samples.

5.3. Results

Here are the obtained experimental results:

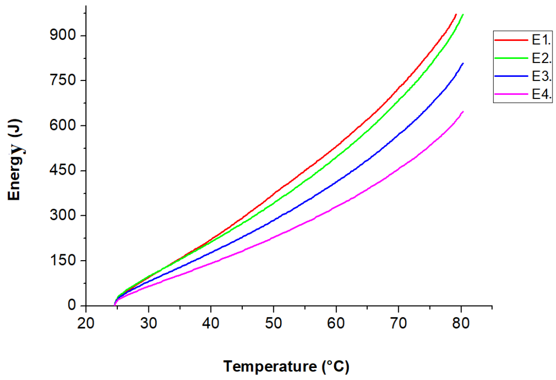

Figure 3: Evolution of energy supplied to water as a function of temperature T.

5.4. Discussion

In figure 3, the curves do not evolve in the same way because of the water hardness. Indeed, the harder the water, the more energy is required to get to the apparatus' temperature of use.

Consequently, drinking water E4 (harder) requires more energy to heat water at the temperature of use of the device.

6. COMPARISON OF ENERGY CONSUMPTION IN THE BUILDING IN TWO CASES

In this comparative study, we will estimate the annual energy consumed by the hydraulic apparatus of our building in the 2 extreme cases: water E4 of hardness TH4 and water E1 of hardness TH1.

6.1. Devices

It is about some domestic appliances of a four-person-house: dishwasher; washing machine; electric kettle; electric water heater; coffee maker.

6.2. Method

The energy required to heat a volume V of water from the temperature T_1 to the temperature T_2 per cycle of each apparatus is calculated using the following relation:

$$E_{cycle} = R.I^2.\Delta t.V/V_0 \qquad (7)$$

V: Volume of water used by the device during a cycle
V_0: Volume of water used during the experiment

Annual energy is deducted for each device by inducing the frequency of use:

$$E_{annual} = 365.f.R.I^2.\Delta t.V/V_0 \qquad (8)$$

f: frequency of use of the device per day

6.3. Results

In the table below, we can read the appliances of a four-person-house.

Table 3: Appliances' annual consumption.

Charact. / Appliances	Volume of water/cycle	Operating T (°C)	Frequency of use(D^{-1})*	Consumed annual energy in MJ: Water E4	Water E1
Dishwasher	20L	50	1	11,33	19,33
Washing machine	50L	40	0,5	9,16	14,16
Electric kettle	1L	100	4	12	18,93
Coffee maker	0,5L	100	1	1,50	2,36
Electric water heater	80L	60	2	133,33	218,66

- Total annual energy for E4: 46,38 kWh
- Total annual energy for E1: 75,85 kWh

* average values derived from devices catalogs

6.4. Discussion

It is confirmed that the annual consumption for hard water is higher.

The relative difference between the two previous energies is written as: $\Delta E/E = 38,85$ %

More than 38% of the energy consumption of a building's hydraulic equipment can be reduced if E4 water is used instead of E1 water.

We note that with fresh water we consume less energy, thus it reduces the electricity bill of our building.

The reduction of limescale in water also extends the life length of our devices and reduces the frequency of maintenance of these devices.

7. CONCLUSION

The results show that it is preferable to introduce a water filtering system (softener), especially in areas where water is hard or very hard. This will be applied to the building's water supply to reduce the energy bill, extend the life length of hydraulic installations, reduce the frequency of maintenance, make soap and detergents more efficient and also improve the quality of drinking water.

To ensure energy efficiency of buildings, it is interesting to:

- know the TH of drinking water used in the building;
- know the effects of parameters that favor the formation of limescale;
- choose the class of devices used in the buildings;
- properly use and adjust devices;
- install a softener, etc.

PERSPECTIVES:

- Studying the profitability of a softener in the same building.
- Analyzing the consequences of the replacement of an electric water heater by a solar one.

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