FAULKNER OPPORTUNITY LLC

PROAGUA PROJECT

Losses Factors in Domestic Water Heaters

Developed by Repowering & Retrofitting Solutions Group S.A. de C.V.

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INDEX

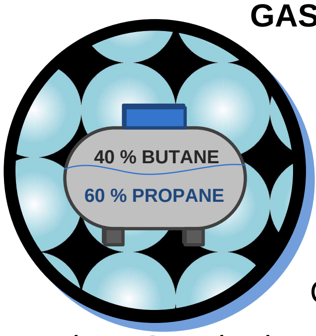
ABSTRACT

The water heaters operation like many other thermal equipments, are associated with presence of losses in efficiency due to different factors, some of them are internal like specific conditions of the heater, but others are external such as the fuel properties and composition.

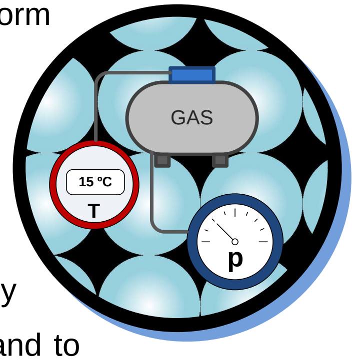
Deficiencies with the internal conditions of the heaters, such as corrosion, presence of sediment and bad combustion are regularly due to lack of maintenance from the user. External conditions such as pressure and chemical composition of the fuel are more complicated to control.

All these alterations to the optimum operating conditions degrade the thermal efficiency of the heater and as a result, carbon dioxide (CO_2) emissions greatly increase when this equipment is used.

The main external variables that affect water heaters efficiency are the gas composition, and the temperature and pressure of them:



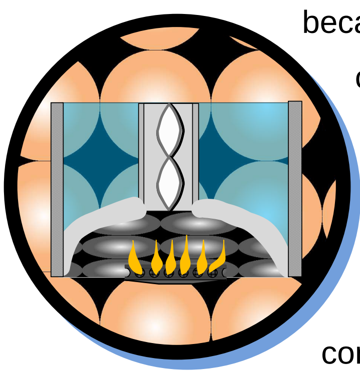
GAS COMPOSITION. Natural gas and LP gas are the fuels usually used in water heaters. Each gaseous fuel emits less or more pollutants into the environment according on their composition. Environment Protection Agency (EPA) Standards provide typical values for the emission factor of CO_2 for these two fuels. However, as indicated by the Official Mexican Standards, these fuels composition regularly met with some ranges. That means that these compositions are never the same so the emission factor will vary. In the case of LP gas this factor varies by 0.56% according to the different combinations; for natural gas this variation is higher: 6.7%.



FUEL TEMPERATURE AND PRESSURE. Properties form all gaseous fuels may vary at different pressure and temperature conditions. LP Gas and Natural Gas burned in various domestic heaters, has a single defining pressure and temperature that defines its properties of the fuel: LHV is one of those. Standard LHV values usually are used to calculate the energy supplied to the heater and to obtain the efficiency. Because of the different LHV values, it is necessary to establish the same conditions between the gas stream and the LHV, also it should be introduced the pressure correction factor and temperature's one. Both factors are directly linked between them and their combination may affect between 5 and 10% the heaters efficiency.

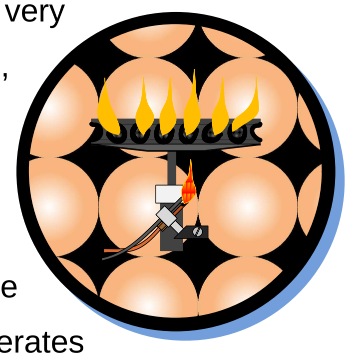
INTERNAL FACTORS TO STORAGE WATER HEATERS

These heaters have three mainly internal factors that affect its efficiency: the calcium carbonate sediments, poor combustion in burners and corrosion. Also the insulation damage could represent in some cases an important factor.

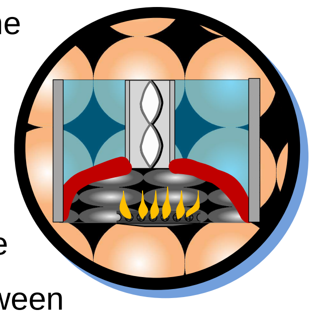


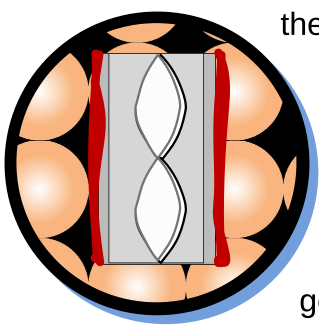
SEDIMENT. The most common is calcium carbonate, which primarily accumulates because of the lack of drainage of the heater, due to its low conductivity it acts as a thermal insulator between the burners and water. As a consequence, exist a considerable decrease of heat transfer so much of the energy is released to the atmosphere and the thermal efficiency of the heater decreases to values far below the original. Under certain conditions, it can generate efficiency losses up to 15%.

POOR COMBUSTION IN BURNERS. This problem is very common in heaters, due to the accumulation of soot in both, air inlets and in burners. As a result fuel fails to burn so the flame temperature does not achieve the temperature it need for the best heat exchange with water. Finally, the heater efficiency decreases as it did not fully exploit the available fuel energy. Under certain conditions, it generates efficiency losses of up to 20%.

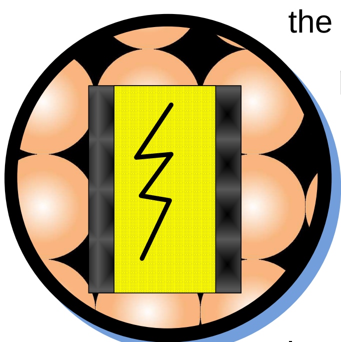


CORROSION. The main cause of this problem is the accumulation of particles in the anode rod or the total corrosion of it. This brings that the heater tank won't have protection against this problem. Like sediment, a layer of corrosion has very low thermal conductivity and therefore acts as a thermal insulator decreasing the heat transfer between the burners and water, therefore, the thermal efficiency is much lower in these conditions. This sediment can appear through all the internal walls of the tank, accentuating the problem at the bottom and at the flue gas pipeline where the heat exchange also occurs. Under certain conditions, it may generate efficiency losses close to 20%.





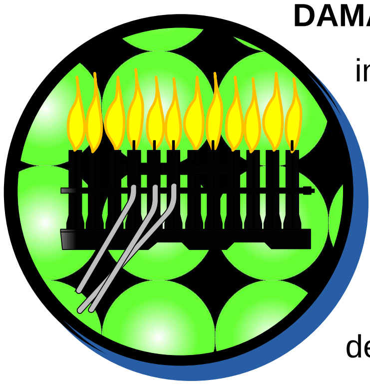
INSULATION DAMAGE. The layer of thermal insulation to prevent heat loss from the hot water to the environment generally consists of polyurethane foam because it is an excellent insulator, but with the passage of time it loses its properties and fails doing its function. As a result, energy is lost in the environment, which is reflected in lower values of efficiency in the heater. Because of it, you may have efficiency losses close to 10%.



It is common that more than one of these factors occur simultaneously, it causes that the thermal efficiency of the equipment in many cases is far below the original. It is very difficult to measure very specific values for the scale of involvement of each variable because it takes several measuring instruments in addition to chemical analysis. Therefore, it results impractical to obtain a global CO_2 emission factor that set all the variables that degrade thermal efficiency. It is advisable to continue with the direct measurements of emissions leaving the exhaust pipe. As they are carried out correctly they reflect all the operational problems that may have a heater without the need to quantify each one of them.

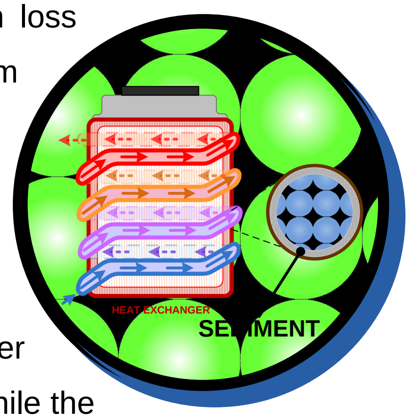
INSTANTANEOUS WATER HEATER-INTERNAL FACTORS

These heaters have two mainly internal factors that affect its efficiency: the damage in burners and the calcium carbonate fouling at the pipelines



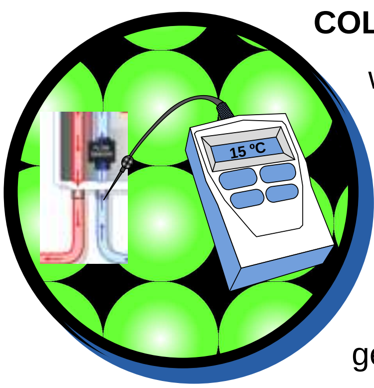
DAMAGE IN BURNERS. It is very common to have problems at instantaneous heaters due to bad function of the burners; the most common reason is the obstruction of the combustion openings and/or air inlets.

The lack of maintenance of burners, affect the quality of hot water. This happens because the flame temperature decreases so the energy transferred to water is reduced. Also the heater's thermal efficiency is lower in these conditions. The results show that as the flame temperature decreases 10 Celsius, the efficiency is reduced by two percentage points; in gross numbers.

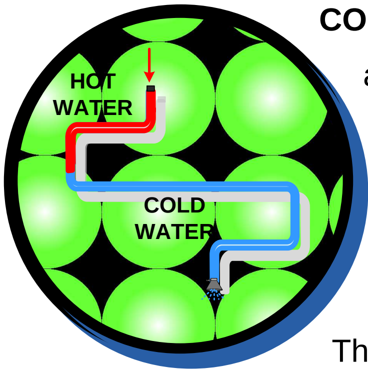


SEDIMENT IN HEAT EXCHANGER. One of the main loss factors in the heater efficiency is due to the calcium carbonate fouling in the pipeline (heat transfer area). The main agents for this fouling are the dissolved impurities in the supply water. As this fouling has a lower thermal conductivity than the pipe material, it reduces the heat transfer as it forms a wall on the inner surface of the pipe, which is the area of heat transfer. While the thickness of inlay grows the thermal transfer will be lost. For every half of a millimeter of thickness in calcium carbonate inlay, the heater loses about 4 percentage points in its efficiency.

Finally, there are other factors that increase the CO_2 production in domestic water heaters; those not impact the heaters efficiency but increases the operation time (for storage eater heaters) or the hot water demand (for instantaneous water heaters), both have how consequence more fuel consumption.



COLD WATER TEMPERATURE. The temperature of supply water (cold water) is an important factor that affects the increase in the CO_2 emissions in the heater. This affects because if the temperature of the water is very low, the consumption of fuel to heat this water will increase. This will depend primarily on the site weather conditions; generally the supply water temperature is less than the site temperature. The results show that for each 1 Celsius less of the temperature of the supply water, the CO_2 emissions increase in the order of 2.5 kg per person in one year.



COLD WATER STORED INTO HOT WATER PIPE. When we are ready to use hot water, at faucet and showers, we realize that hot water comes after a certain time. This "cold water" already passed through the heater before, but it was stocked into the pipeline before it was used and lost its energy.

The volume of water into the pipe between the heater and the devices, had consumed a certain amount of energy from the fuel in the heater, which means there was a corresponding amount of CO_2 emissions due to this combustion.

CO_2 emissions increase in proportion to the distance between the heater and devices, so in those houses where exists a great distance in hot water pipelines, there will be a considerable amount of emissions produced by this factor.

CO_2 EMISSION FACTORS FOR LP AND NATURAL GAS COMPOSITION

All fossil fuels emit less or more pollutants into the environment depending on certain variables, but mainly its chemical composition.

For Faulkner Project, the quantity of specific gases and carbon dioxide (CO_2) can be calculated using an agent called emission factor. That is, in each heater can be calculated the amount of carbon dioxide emissions by multiplying its fuel consumption by their respective CO_2 emission factor (specific to each fuel). This method is widely used, however, this emission factor can be affected mainly by the fuel composition, most carbon means higher CO_2 emissions.

In this section, the behavior of carbon dioxide emissions in response to the changes of the chemical composition of fuels used at the heaters from Faulkner Project study is studied.

For both fuels, LPG and Natural Gas this emission factor changed depending on the variation of their composites according to the composition ranges established at Mexican Official Standards:

- LPG, the emission factor varies from 2.998 to 3.015 kg of CO_2 per kg of LPG burned, it means, a variation of 0.564%.

- Natural Gas, its variation is from 2.606 to 2.783 kg of CO_2 per kg of Natural Gas burned, which represents a variation of 6.761%.

This suggests that the measurement of these data in the chimney of each heater shed more reliable results than the use of emission factors for this project.

LP Gas

LP Gas is an oil derivative and it consists mainly of propane, butane and other compounds, but is unique among commonly used fuels. The ***Mexican Official Norm NOM-086-SEMAR-SENER-SCFI-2005***[1] ***"Specifications of fossil fuels for environmental protection"*** indicates the compounds range for the composition of LPG as shown below:

Composite	Range
Propane	60% mínimum
Butane	40% máximum
Ethane	2.5% máximum

LP gas Composition. Source: NOM-086-SEMAR-SENER-SCFI-2005

If you look closely at the compounds that make up the LPG according to this standard, we realize that each of these compounds is composed of the following percentages of Carbon (C) and Hydrogen (H).

Composite	Formula	% C	% H
Propane	C_3H_8	81.81	18.19
Butane	C_4H_{10}	82.76	17.24
Ethane	C_2H_6	80	20

LP gas composition, percentages of Carbon and Hydrogen

[1] *http://www.ordenjuridico.gob.mx/Federal/PE/APF/APC/SEMARNAT/Normas/Oficiales/2006/30012006(1).pdf*

This means that the maximum and minimum range of carbon content in the LP gas is:

Range	% C	Supposed Composition
Mayor	82.26	40% de Buthane 60% de Propane
Menor	81.79	2.5% de Ethane, 0% de Buthane 97.5% de Propane.

Maximum and minimum range of carbon content in the LP gas

That is, from one to another range, the variation of Carbon content in the fuel is 0.47%. In fact, this variation is very small but it must be verified that the change of carbon dioxide emissions between the two ranges for LP gas is insignificant too with a combustion analysis.

Natural Gas Natural gas is a nonrenewable energy source formed by a gas mixture. It is commonly found in oil fields, associated or non-associated with oil, also it is found in coal deposits. Although its composition varies depending on the site which it is extracted, is mainly composed of methane. The ***Mexican Official Standard Draft NOM-001-SECRE-2008***[2] ***"Natural Gas Specifications"*** details the minimum and maximum limits of the components for natural gas, as follows:

Composite	Ranges	
	South Zone	Rest of country
Methane	83% mínimum	84% mínimum
Ethane	11% máximum	11% máximum
Carbon dioxide	3% máximum	3% máximum
Nitrogen	5% máximum	4% máximum
Total inert (CO_2+ N_2)	5% máximum	4% máximum
Oxygen	0.2% máximum	0.2% máximum

Minimum and maximum limits of the components for natural gas.
Source: **NOM-001-SECRE-2008**

If now for the natural gas are thoroughly analyzed the compounds that comprise it according to the standard, we realize that each of these compounds is composed

[2] *http://www.ordenjuridico.gob.mx/Federal/PE/APF/APC/SENER/Proyectos/2009/23022009(1).pdf*

of the following percentages of Carbon (C), Hydrogen (H), Nitrogen (N) and Oxygen (O).

Composite	Formula	% C	% H	% N	% O
Methane	CH_4	75	25	0	0
Ethane	C_2H_6	80	20	0	0
Carbon dioxide	CO_2	27.3	0	0	72.7
Nitrogen	N_2	0	0	100	0
Oxygen	O_2	0	0	0	100

Percentages of Carbon (C), Hydrogen (H), Nitrogen (N) and Oxygen (O) in NG

This means that the minimum and maximum ranges in the content of C for the Natural Gas are:

Range	% C	Supposed Composition
Major	75.94	89% de Methane 11% de Ethane
Minor	71.10	94.8% de Methane, 5% de Nitrogen 0.2% de Oxygen

Minimum and maximum ranges in the content of C for the Natural Gas

In this case, the variation in C content between each range is 4.84%.

On the web page of **CONUEE**[3] are shown the typical composition for natural gas in Mexico: (73.07% C, 23.65% H_2, 3.28% N_2), which is similar to the composition a natural gas compound of 84% methane, 11% ethane, 3% nitrogen and 2% CO_2.

[3] *Comisión Nacional para el Uso Eficiente de la Energía*
http://www.conae.gob.mx/wb/CONAE/CONA_694_a2_tablas_y_figura?page=2

Emission Factor

The emission factor (ratio between the amount of pollution emitted to the atmosphere and a unit of primary energy) is obtained to determine the amount of CO_2 emissions generated from the burning of different fuels on household heaters.

Earlier in Faulkner Project we referred to the *Environment Protection Agency Standards:* ***EPA-AP42 c01s04***[4] *and* ***EPA-AP42 c01s05***[5] which provides the CO_2 emission factor of natural gas and the LP gas.

As we've seen in this document, the use of emission factors is not necessarily the best way to calculate the emissions from the fuels, but given the lack of continuous measurements of emissions on the heaters chimneys, it is the only viable option.

Even considering that the emission factors calculations give good results, there are several other simplifications and assumptions that affect the accuracy of the calculations.

Here we address these factors and their possible impact on the emissions calculation. For any combustion process, the exact percentage of carbon in the fuel directly affects its CO_2 emissions.

To determine this emission factor for different compositions of natural gas and LP gas and understand this sensitivity, it is necessary to resort the calculating of this factor by developing a combustion process, as detailed below:

[4] *http://www.epa.gov/ttnchie1/ap42/ch01/final/c01s04.pdf*
[5] *http://www.epa.gov/ttnchie1/ap42/ch01/final/c01s05.pdf*

Combustion The combustion is a set of oxidation reactions with heat release, which occur between two elements: the fuel, which can be a solid, liquid or gas and the oxidant. The oxidation process of combustion occurs quickly and with the presence of flame, with the characteristic of this flame should stay steady.

Most of fuels, whether they are solid, liquid or gaseous, consist essentially of Carbon (C) and Hydrogen (H); in addition to these major components are others like Sulfur (S), Nitrogen (N_2), Oxygen (O_2), Humidity (H2O) and so on. In practice, the fuels can be defined as CxHy.

For the Faulkner Project case, the two ***fuels*** commonly used in domestic heaters in Mexico are gaseous: Natural Gas (NG) and Liquefied Petroleum Gas (LPG).

The universal ***oxidant*** is oxygen because as the fuel burns, is combined with oxygen to form carbon dioxide (CO_2), water (H_2O), and other gases. Nitrogen (N_2) is considered as an inert mass, at high temperatures it may be formed nitrogen oxides in small amounts (about 0.01%), so these are not considered in the analysis. In practice, air is used as oxidizer, since it is composed, almost by 21% Oxygen (O_2) and 79% Nitrogen (N_2).

The ***activation energy*** is the trigger element for the reaction of combustion. In gas heaters studied here it is obtained by pilot flame.

Stoichiometric combustion is a complete combustion carried out with the strict quantity of oxygen, ie air used in combustion is the minimum necessary that contain the amount of oxygen for make the complete oxidation of all fuel components.

Through this stoichiometric combustion and the volumetric mass relationships between reactants and products it can be determined: the required amount of air for combustion and the combustion products and their composition

However, this kind of combustion is practically impossible, which forces to operate with excess of air to achieve a complete combustion. In this case the amount of air supplied is higher than the one for the stoichiometric combustion. When more air is used than the strictly necessary, in the products of the combustion will give the presence of oxygen (O_2).

To obtain a proper combustion is achieved a good mix of the fuel with the air. In this sense the gaseous fuels mix more readily than liquids and these in turn more than solids. For this reason, the combustion of gaseous fuels can obtained with smaller amounts of air excess.

From these premises, it is considered a complete combustion of LPG and Natural Gas in our analysis. The expression that represents complete combustion is:

$$C_xH_y + n_1(O_2 + N_2) \rightarrow xCO_2 + \left(\frac{y}{2}\right)H_2O + 0.21(n_1 - n)O_2 + 0.79n_1N_2$$

LP Gas

From the foregoing, the CO_2 emissions for LPG were calculated, assuming the two compositions shown in the higher and lower ranks. These are the results:

In the higher range the emissions are 3.015 kg CO_2 per kg of consumed fuel. What gives us a value of 1688.40 kg of CO_2 per m^3 of LPG, as shown below:

$$3.015\frac{kg\ CO_2}{kg\ GLP} * 560\frac{kg\ GLP}{m^3\ GLP} = \ 1688.40\ \frac{kg\ CO_2}{m^3\ GLP}$$

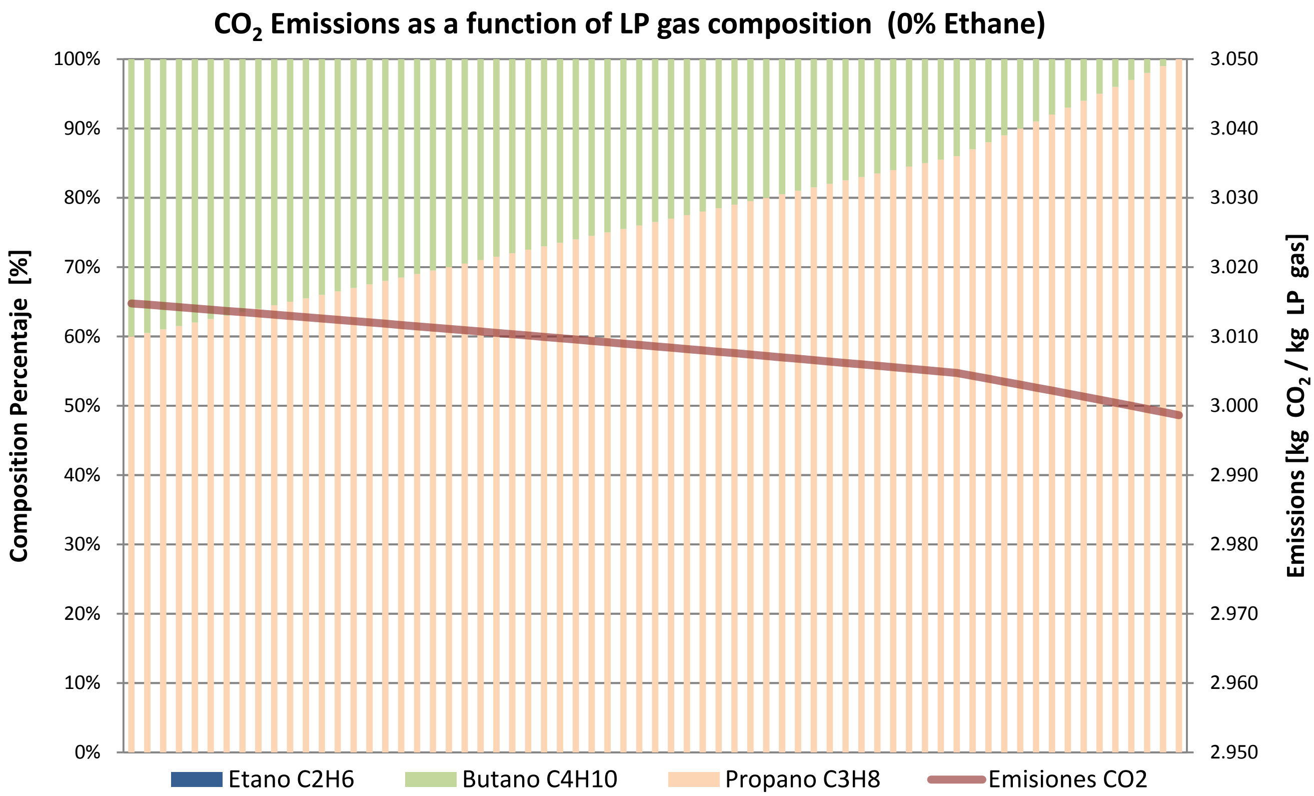
n the case of lower rank the emissions are 2.998 kg CO_2 per kg of consumed fuel. This give us a value of 1678.88 kg of CO2 per m^3 of LPG, as illustrated below:

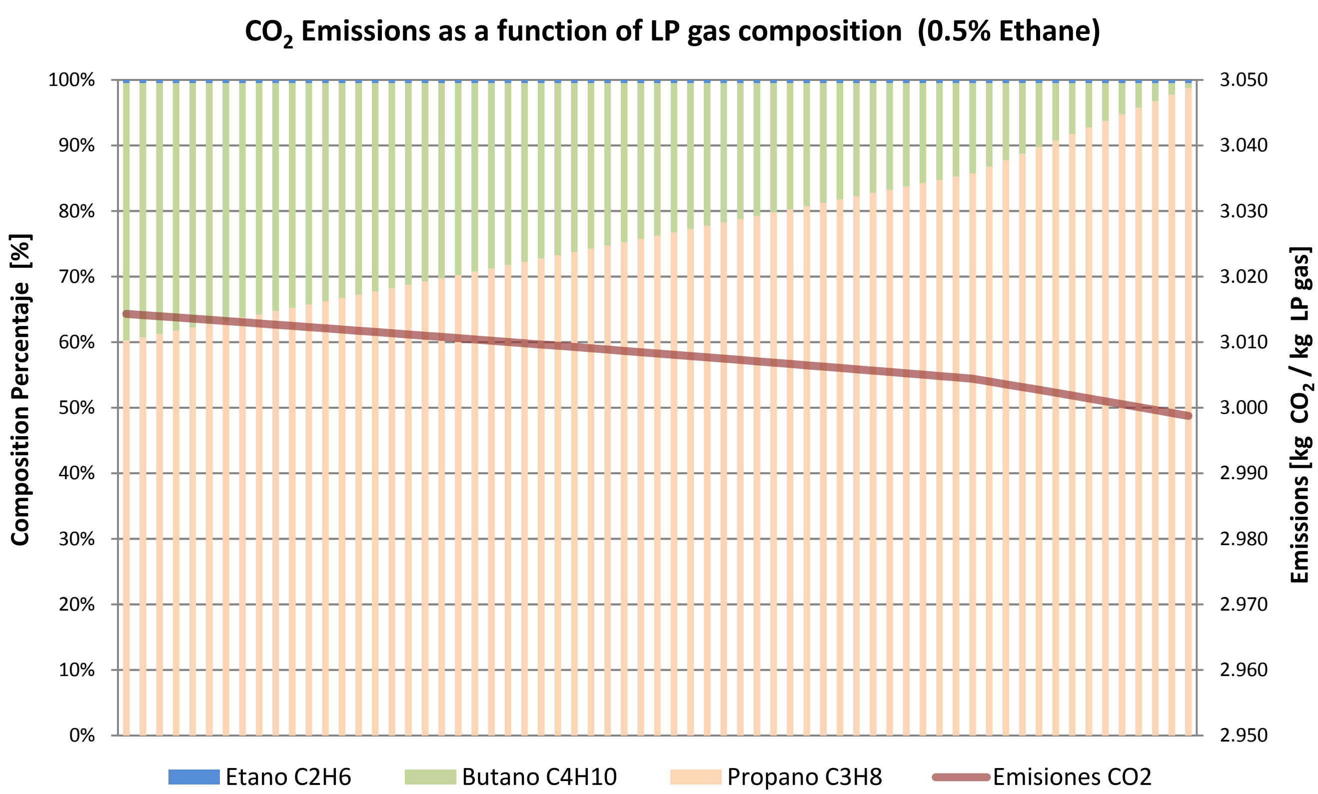
$$2.998\frac{kg\ CO_2}{kg\ GLP} * 560\frac{kg\ GLP}{m^3\ GLP} = \ 1678.88\ \frac{kg\ CO_2}{m^3\ GLP}$$

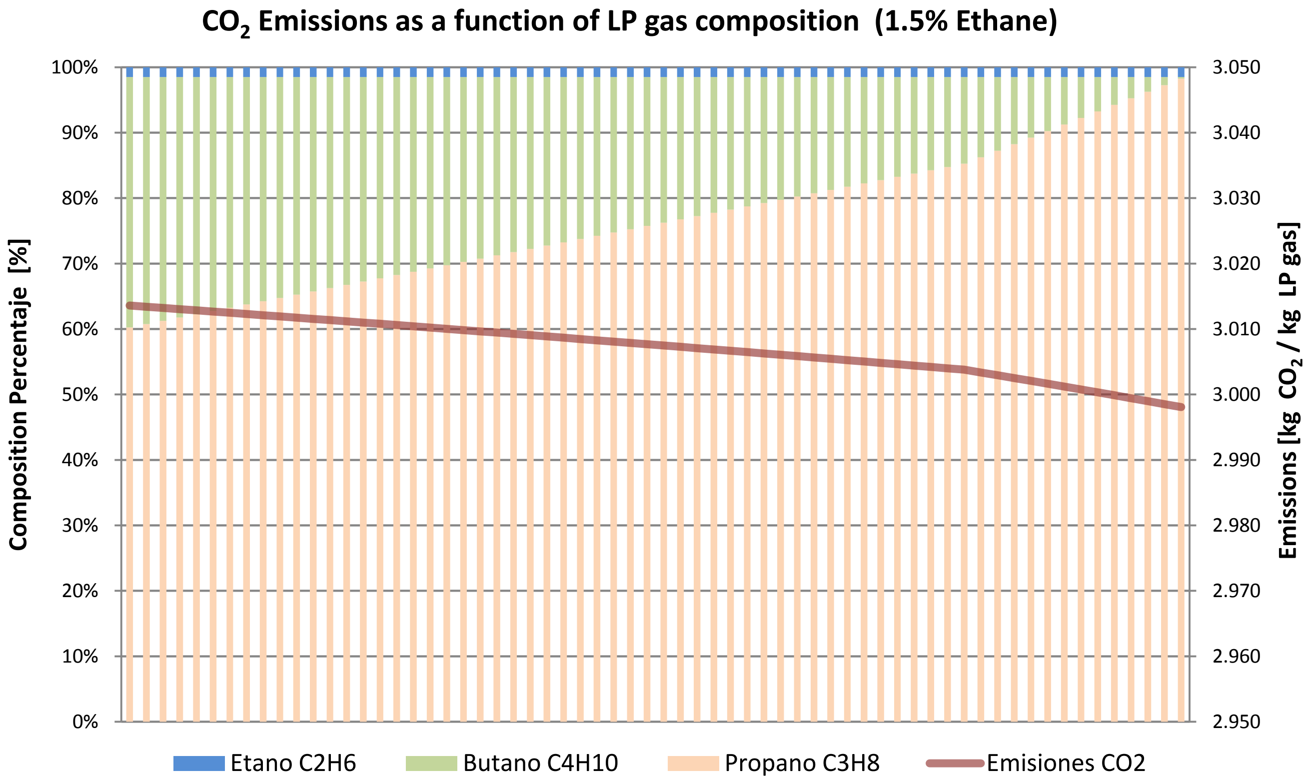
Annex 1 shows the calculation of CO_2 emissions due to the use of LPG in their highest and lowest ranges of Carbon composition..

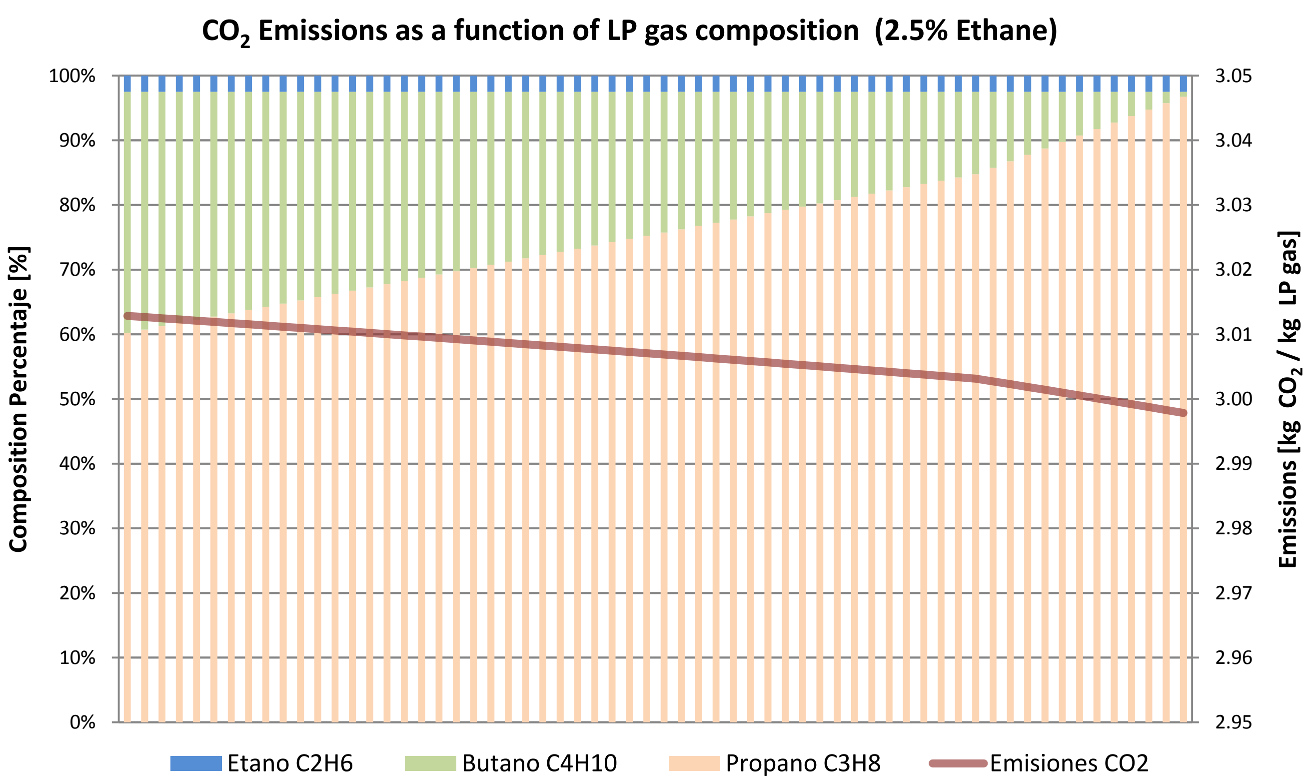
The variation in the emission factor calculated between the two ranges for LPG is 0.564%.

This means that emissions of carbon dioxide gas for LP gas are almost always the same no matter the difference in the composition of this fuel.


CO_2 Emissions as a function of LP gas composition (0% Ethane)
Composition Percentaje [%]
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
3.050
3.040
3.030
3.020
3.010
3.000
2.990
2.980
2.970
2.960
2.950
Emissions [kg CO_2 / kg LP gas]
Etano C2H6
Butano C4H10
Propano C3H8
Emisiones CO2


CO_2 Emissions as a function of LP gas composition (0.5% Ethane)
Composition Percentaje [%]
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
3.050
3.040
3.030
3.020
3.010
3.000
2.990
2.980
2.970
2.960
2.950
Emissions [kg CO_2 / kg LP gas]
Etano C2H6
Butano C4H10
Propano C3H8
Emisiones CO2


CO2 Emissions as a function of LP gas composition (1.5% Ethane)
Composition Percentaje [%]
Emissions [kg CO2 / kg LP gas]
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
3.050
3.040
3.030
3.020
3.010
3.000
2.990
2.980
2.970
2.960
2.950
Etano C2H6
Butano C4H10
Propano C3H8
Emisiones CO2


CO2 Emissions as a function of LP gas composition (2.5% Ethane)
Composition Percentaje [%]
Emissions [kg CO2 / kg LP gas]
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
3.05
3.04
3.03
3.02
3.01
3.00
2.99
2.98
2.97
2.96
2.95
Etano C2H6
Butano C4H10
Propano C3H8
Emisiones CO2

Natural Gas

Now, from the considerations for natural gas, the same calculation of CO_2 emissions for LPG was made for the natural gas one. Assuming the two compositions shown in the higher and lower ranks as to the amount of carbon is concerned, these are the following results:

In the higher range the emissions are 2.783 kg of CO_2 per kg of consumed fuel. What gives us a value of 1.6698 kg CO_2 per m^3 of natural gas, as illustrated below:

$$2.783\frac{kg\ CO_2}{kg\ GN} * 0.6\frac{kg\ GN}{m^3\ GN} = \ 1.6698\,\frac{kg\ CO_2}{m^3\ GN}$$

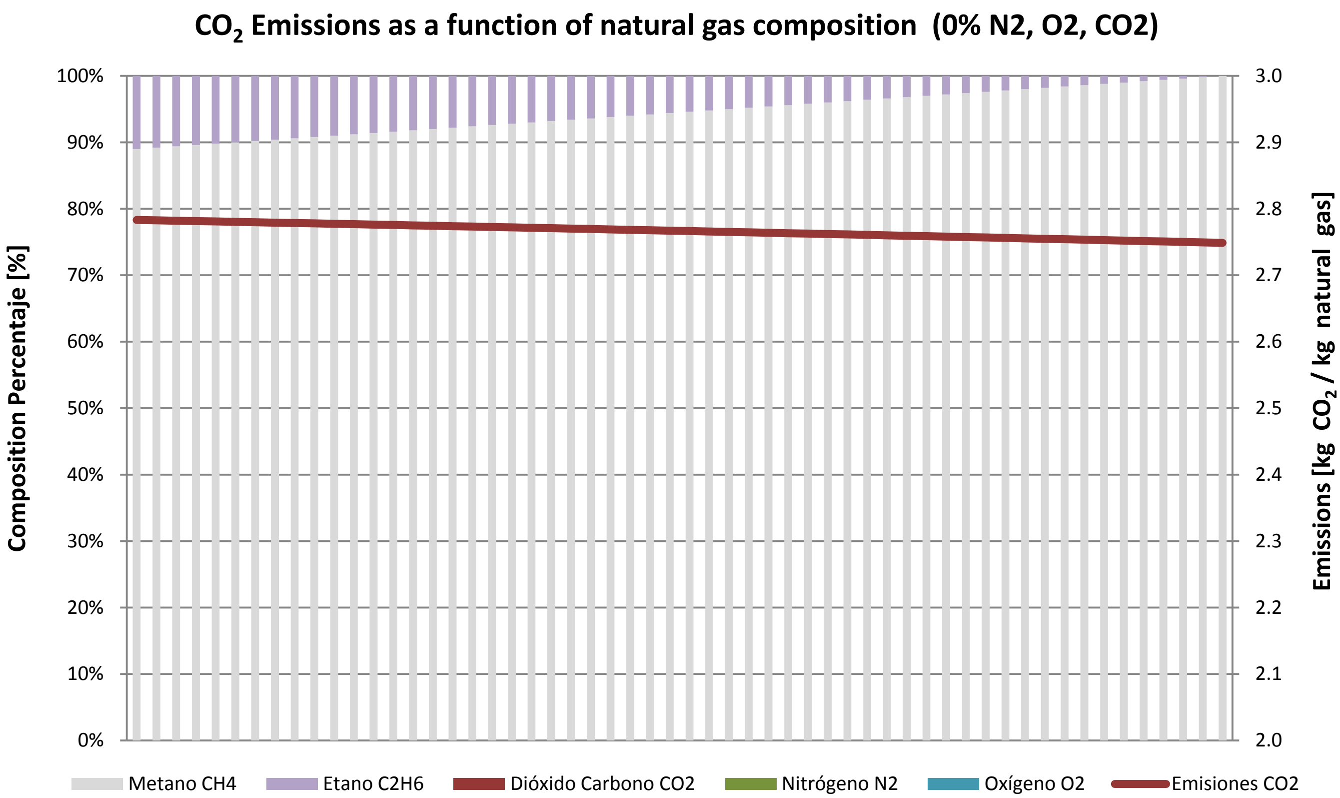
In the case of lower rank, the emissions are 2.636 kg of CO_2 per kg of fuel consumed. What gives us a value of 1.5636 kg CO $_2$ per m^3 of natural gas, as illustrated below:

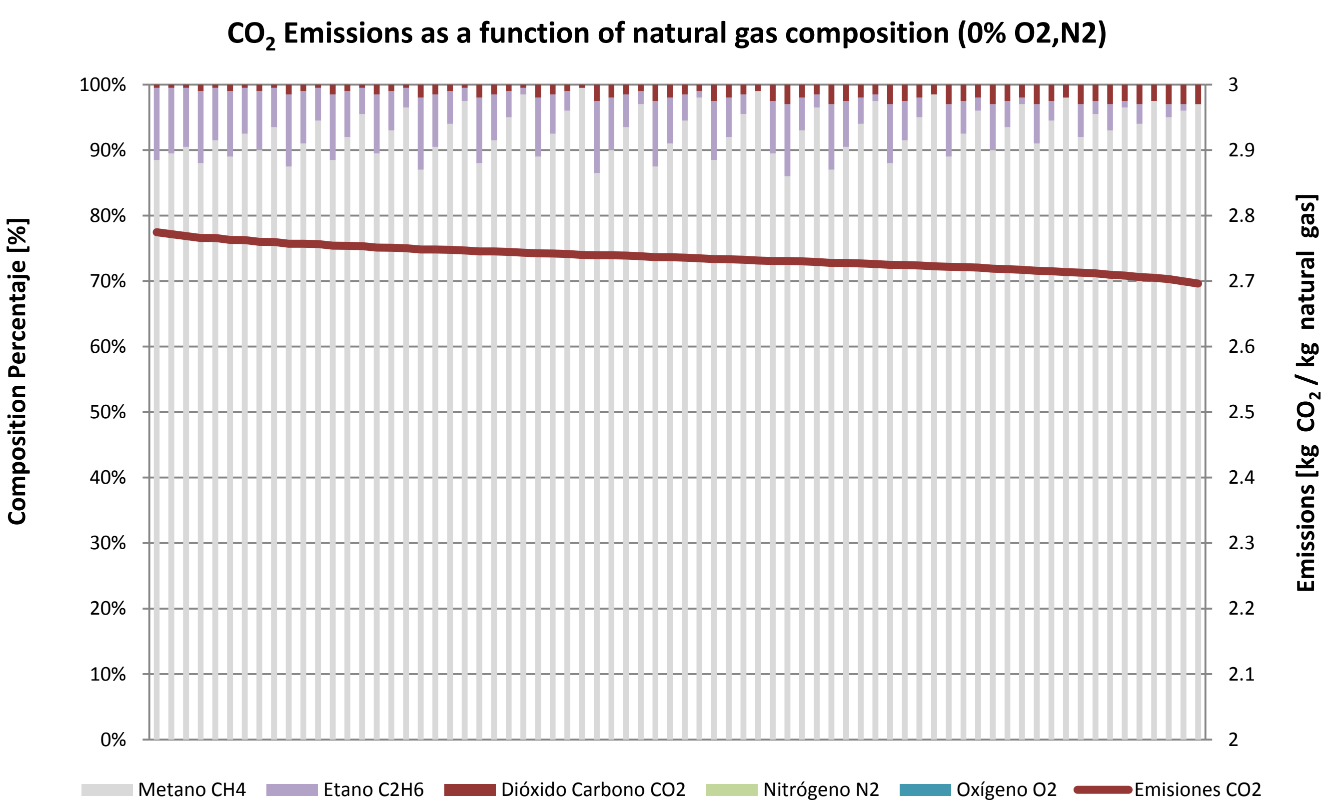
$$2.606\frac{kg\ CO_2}{kg\ GN} * 0.6\frac{kg\ GN}{m^3\ GN} = \ 1.5636\,\frac{kg\ CO_2}{m^3\ GN}$$

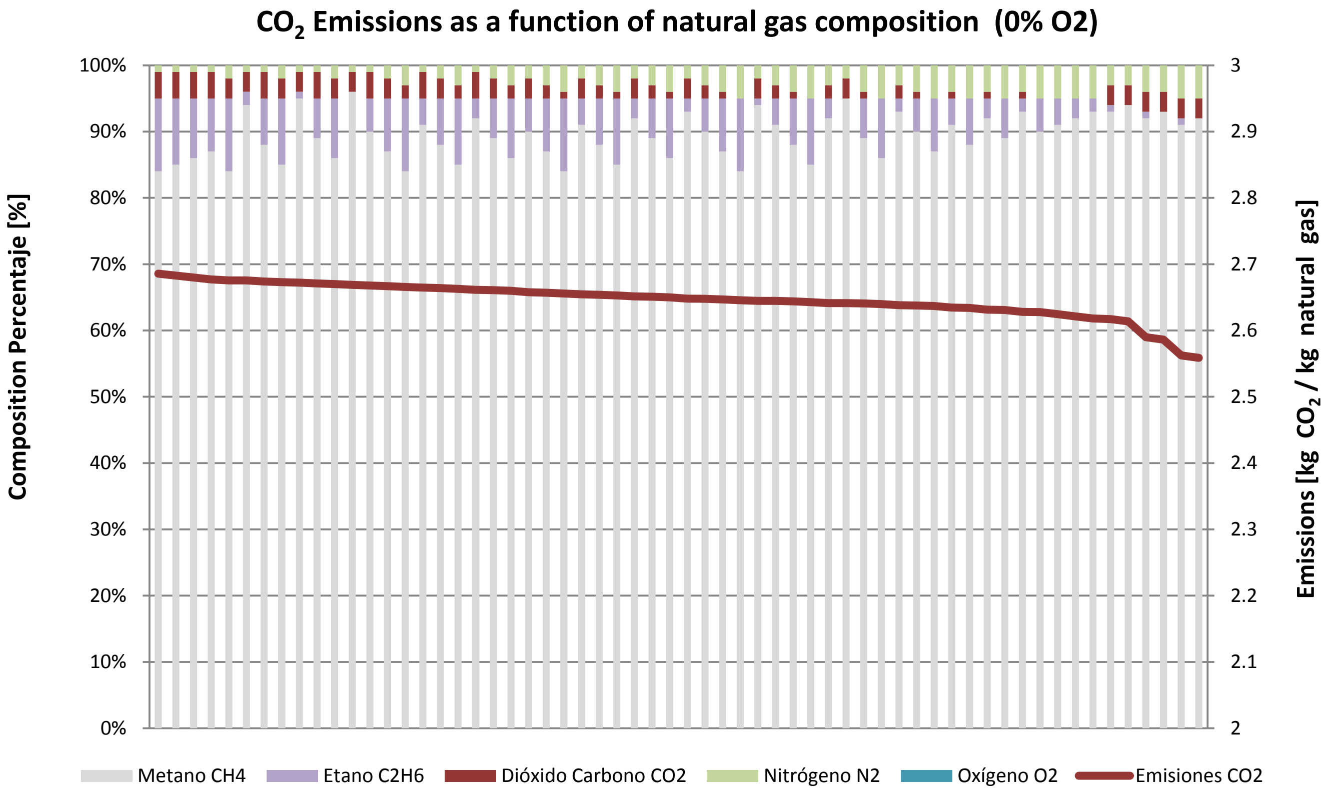
Annex 2 shows the calculation of CO $_2$ emissions by using natural gas at higher and lower ranks. In the case of Gas Natural, the variation in the emission factor calculated between these two ranks is 6.76%.

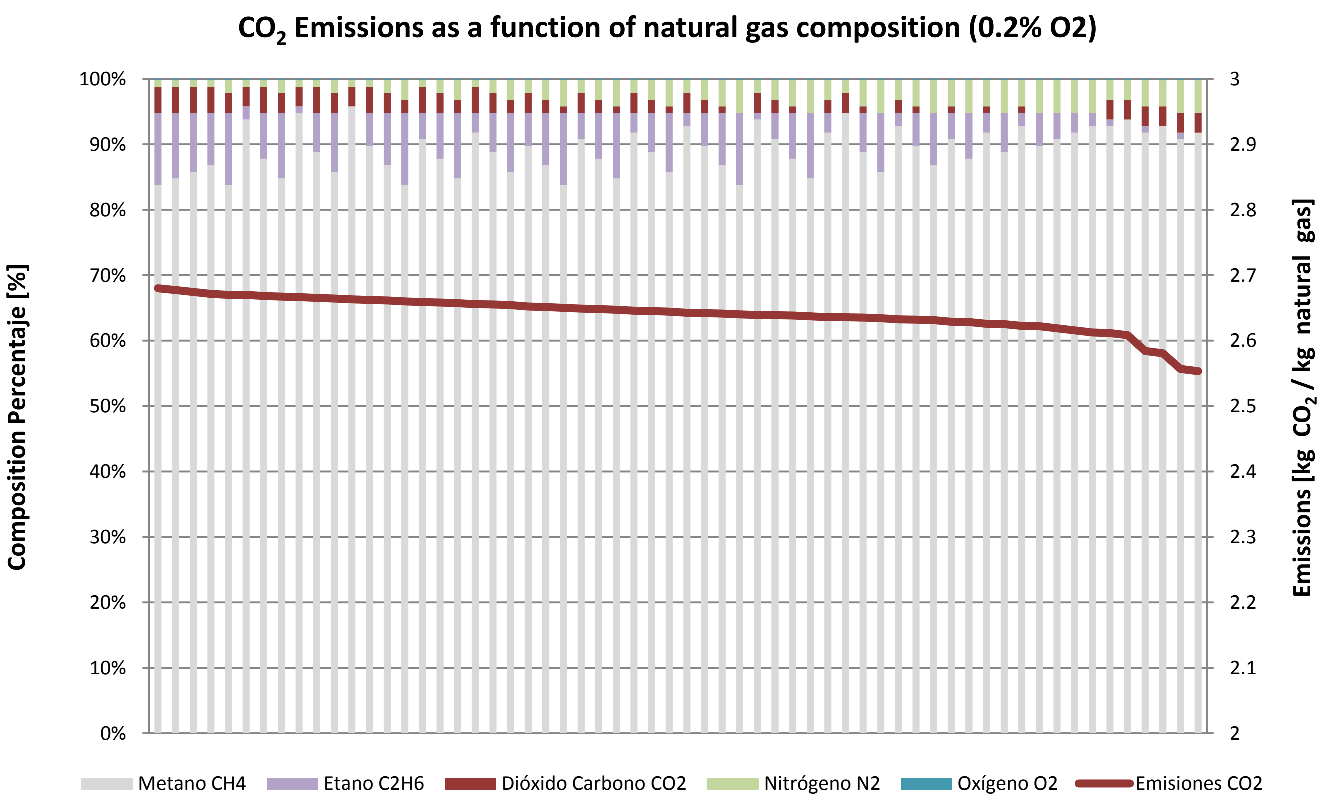
This means that carbon dioxide emissions for natural gas vary a lot with different compositions. This variation is great if what we are measuring are the emissions of the heaters in one million households in Mexico, because the 6.76% of one million are 67.600 kg CO $_{2,}$ which can't be negligible.

Although higher and lower ranks in the carbon composition on fuels indicate the extremes that have on carbon dioxide emissions, annex 2 shows some charts broken down in different compositions of fuel and their respective emission factor.


CO2 Emissions as a function of natural gas composition (0% N2, O2, CO2)
Composition Percentaje [%]
Emissions [kg CO2 / kg natural gas]
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
Metano CH4
Etano C2H6
Dióxido Carbono CO2
Nitrógeno N2
Oxígeno O2
Emisiones CO2


CO2 Emissions as a function of natural gas composition (0% O2,N2)
Composition Percentaje [%]
Emissions [kg CO2 / kg natural gas]
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
Metano CH4
Etano C2H6
Dióxido Carbono CO2
Nitrógeno N2
Oxígeno O2
Emisiones CO2


CO2 Emissions as a function of natural gas composition (0% O2)
Composition Percentaje [%]
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Emissions [kg CO2 / kg natural gas]
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
Metano CH4
Etano C2H6
Dióxido Carbono CO2
Nitrógeno N2
Oxígeno O2
Emisiones CO2


CO2 Emissions as a function of natural gas composition (0.2% O2)
Composition Percentaje [%]
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Emissions [kg CO2 / kg natural gas]
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
Metano CH4
Etano C2H6
Dióxido Carbono CO2
Nitrógeno N2
Oxígeno O2
Emisiones CO2

FUEL CORRECTION FACTORS

One difficult aspect to quantify is the gas flow and its corresponding lower heating value (LHV), at the conditions that are operating domestic heaters, either natural gas or LP; in storage tank or instantaneous water heaters; in order to obtain efficiency.

The LHV of gaseous fuels varies with the pressure at which gas is being supplied, so is necessary to establish reference conditions, to calculate the energy supplied by it.

The reference conditions normally used are the called *ISO*. *Normal's* are also used, among others. All of them make reference to the LHV and reported in various bibliographies.

To accurately estimate the efficiency of domestic heaters, it´s necessary to use a gas flow value corresponding to the LHV conditions. The gas flow value that is usually measured with instruments has units of m^3/min.

There are two factors that have to be applied after a measurement of gas flow; pressure correction factor and temperature correction factor for gas.

Official Mexican Standard NOM-003ENER-2000 Thermal Efficiency of Water Heaters for residential and commercial use. Limits, Test Method and Labeling provides the methodology for calculate the domestic water heaters efficiency, R & R extends the analysis section of fuel flow factors.

Is important to mention that in Project Faulkner, there are a variety of ways to have a gas supply, it could be by gas pipe lines (for Natural Gas) or storage gas tank (for LP Gas). For that, result difficult to make a study like this.

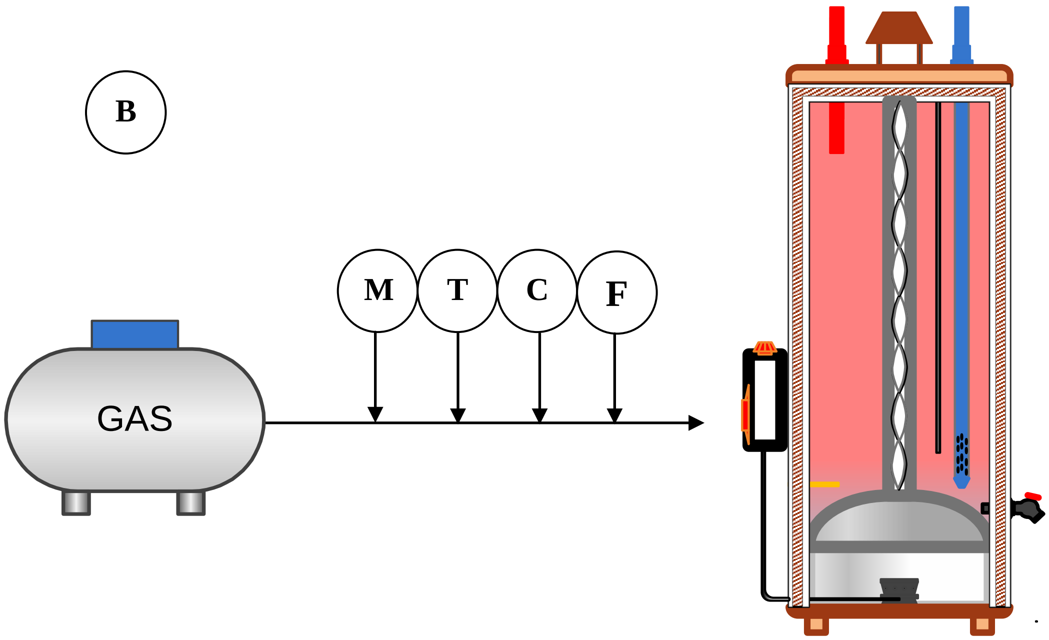
Development

In order to illustrate the instrumentation required to obtain the values to calculate the correction factors of fuel flow, we present the following development.

Equipment:

- *Chromatograph* or another gas analyzer, to obtain the gas composition
  How a percentage of each element that composes it, with units of percentage [%]
- *Differential Manometer*, to determine the pressure of gas flow that arrives to water heater, with units of manometric bares [barm].
- *Barometer*, to know the atmospheric pressure in the place, with units of barometric bares [bara].
- *Termopar*, to determine the temperature of gas flow, with units of Celsius degree [ªC].
- *Flow Meter*, to determine the gas flow rate, with units of [m^3 / s].

The previous measurement equipment, are the ones to obtain the information necessary to calculate the gas flow factors. The following scheme shows how should be the implementation in a storage water heater, but this methodology is also applicable to instantaneous water heaters; with interchangeable storage tank or stationary gas, and vice versa.



Implementation in a storage water heater

Where the letters B, M, T, C and F, corresponds to Barometer, Manometer, Thermopar, Chromatograph and Gas Flow Measurement respectively.

The diagram represents a storage tank water heater, however this methodology is also applicable to instantaneous water heaters, whit a supply of Natural Gas o LP Gas for twice types of water heaters.

The measurements have to be realized during the operation of the water heater, only the barometer measurement could be in any moment in the place.

The finality of this methodology is to represent the job necessary to determine the gas flow factors, and not to make understand how to do the measurements whit each one of equips.

Analysis

From efficiency expression we know that the denominator corresponds to the Fuel Power; Flow Fuel and Low Heating Value of them:

$$\eta = \frac{m_{water} Cp \Delta T}{V_{fuel} LHV}$$

From here to the end in this section, we will work with denominator only. Where V_{comb} [m^3/min] is the gas flow measurement, it could be Natural or LP Gas and LHV [KJ/m^3] is the low heating value of the fuel at ISO conditions.

If we do a dimensional analysis, have the next:

$$[V_{fuel} * LHV]_u = [\left(\frac{m^3{}_m}{min}\right)\left(\frac{KJ}{m^3{}_{ISO}}\right)]$$

Where “m” and “ISO” subscripts, corresponds to a measurement and ISO condition respectively.

Is necessary to introduce the Ideal Gas Equation, to determine the same conditions (ISO conditions) between gas flow and low heating value of the gas:

$$PV = mRT$$

Where, P [Pa] is the gas pressure, V [m^3] is the gas volume, R [kJ/kg*ºC] is the gas ideal constant and T [ºC] is the gas temperature, all of them define one gas state.

Whit this, now we have to establish two gas state equations, once the gas flow at measurement conditions and other for ISO conditions:

$$P_m V_m = mRT_m$$

Y

$$P_{ISO}V_{ISO} = mRT_{ISO}$$

Although, if the ideal gas constant is the same for twice states; for a same mass flow between measurements and ISO conditions, we have the next:

$$\frac{P_m V_m}{T_m} = \frac{P_{ISO}V_{ISO}}{T_{ISO}}$$

The relation between gas flow in measurement and ISO conditions, if $V_{ISO}=m^3{}_{ISO}$ and $V_m=m^3{}_m$ is:

$$\frac{m^3{}_{ISO}}{m^3{}_m} = \frac{V_{ISO}}{V_m} = \left(\frac{P_m}{P_{ISO}}\right)\left(\frac{T_{ISO}}{T_m}\right)$$

Finally, the gas flow measurement, V_m, have to be converted at the same conditions of the low heating value of the gas (ISO) with the past expression. Where identify two factors, one corresponds to a pressures relation and the other to a temperatures relation.

Temperature Gas Correction Factor

The Temperature Gas Correction Factor of the fuel is defined by the next expression:

$$F_T = \frac{T_{ISO}}{T_m}$$

Where variables T_{ISO} [ªC], is the gas temperature at ISO conditions of the fuel and T_m [ªC], is the measurement gas temperature.
The ISO temperature of the Natural Gas and LP Gas is 15.5 ªC.

Pressure Gas Correction Factor

The Pressure Gas Correction Factor of the fuel is defined by the next expression:

$$F_P = \frac{P_m + P_{BAR}}{P_{ISO}}$$

Where the variables, P_m [Barm], is the manometric measurement gas pressure in the pipe line, P_C [Bara], is the absolute barometric pressure of the place and P_{ISO} [Bara], is the absolute ISO pressure.

The ISO pressure for Natural Gas and LP Gas is 101,325 [Pa] or 1.01325 [Bara].

Gas Flow Correction Factors and their effect in Water Heaters Efficiency

Pressure gas correction factor

The main variable of pressure gas correction factor is the measurement gas pressure, because the other two could be considered like constants.

The gas pressure measurement values are between the nominal values of gas supply to commercial water heaters; it normally is around 2,670 [Pa] for LP Gas and 1,700 [Pa] for Natural Gas, both manometrics. Moreover, due to the altitude of Mexico City, barometric pressure is low, 79-80 kPa, therefore, it is expected that the **pressure correction factors almost always have a value less than one.**

Temperature correction factor

The temperature correction factor has only one variable, the measured temperature of the gas because the gas temperature is ISO known information. This factor will always have a value greater than or very close to one, as the average gas temperature is equal and slightly higher than the ambient temperature of Mexico City.

Impact on Efficiency

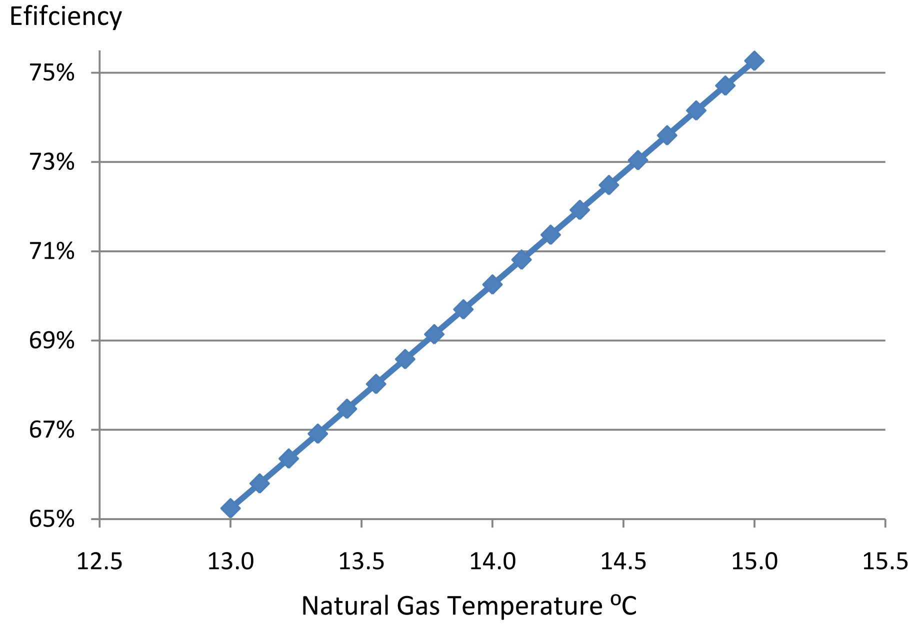
To illustrate the impact of these factors on efficiency, an exercise was carried out using as a starting point the data plate of a natural gas water heater (*IUSA)*, as if it were new. The exercise consists in vary the temperature of the gas and them determine the corresponding pressure.

The information of the heater is:

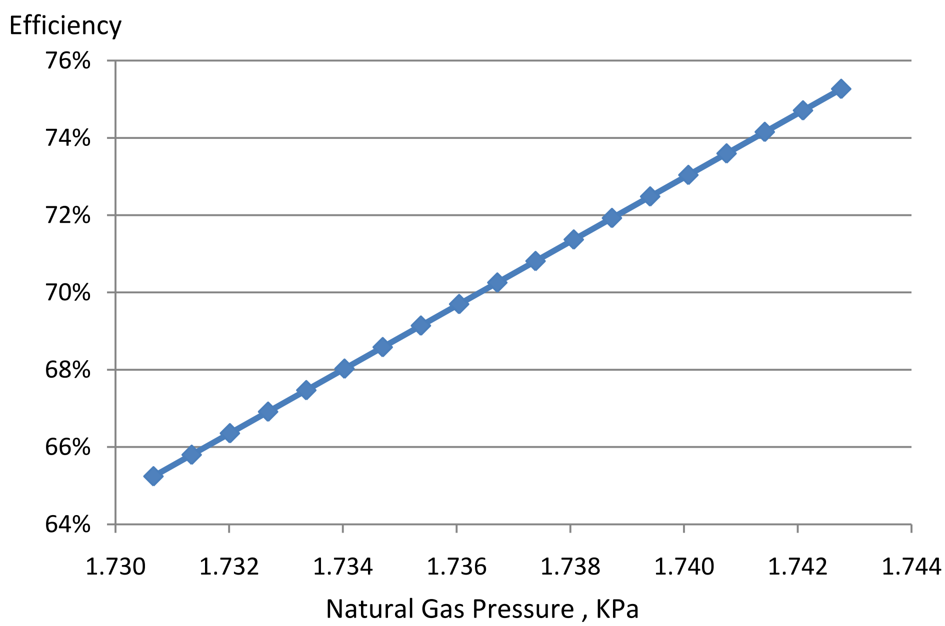
HEATER INFORMATION		
DATA PLATE	Value	Units
Temperature rise	25.0	ºC
Heater capacity	40.0	liters
Recovery time	24.0	min
Thermal power	3.5	kW
Thermal capacity of water	4,186.0	J/kgºC
Fuel type	Gas Natural	---

ISO Temperature	15.5	C
ISO Pressure	101,325.0	Pa
Barometric pressure@DF	76,970.0	Pa

Importantly, the results are only an approximation of the behavior of the efficiency, under the effect of these factors.



Efficiency Performance according to Natural Gas Temperature



Efficiency Performance according to Natural Gas Pressure

** Table of Results and considerations for implementation of the graph, Annex 3*

INTERNAL CORRECTION FACTORS FOR STORAGE WATER HEATERS

Storage heaters require a preventive maintenance that is rarely granted. Their daily operation makes it susceptible to the formation of agents that reduce its performance over time. If moreover, coupled with the lack of maintenance, we see that in most cases heaters exceed their useful life, we have as a result low efficiency equipment, with increased consumption of LPG / Natural.

The main factors that affect efficiency of storage tank water heaters are:

• Corrosion in the tank wall
• Calcium carbonate deposits at the bottom of the tank
• Deterioration of burners

Another factor that can affect efficiency, is the deterioration of thermal insulation, however, this is not a common problem in the heaters, but could be presented.

Below are the aforementioned factors, the rise and how their impact on efficiency.

HEAT TRANSFER LOSSES FACTORS AT THE BOTTOM OF THE TANK

Mineral Sediments

The drinking water distributed to households in Mexico City that is used to feed common water heaters, both storage and instantaneous, contains a large amount of salts and minerals. All these impurities are washed away along its trajectory in the supply piping system of water distribution network in the city, water tanks and house pipes before coming to the heaters. Moreover, as established by the Mexican Official Standard NOM-127-SSA1-1994. "Environmental Health, water for human use and consumption - permissible limits of quality and processes that must be applied for drinking water, water from its source can contain many elements, for its abundance in nature, carbonate calcium ($CaCO_3$) is one of the main components dissolved in water

Thus, a considerable amount of particles enter into the heaters, especially in storage water heaters, where sedimentation is common minerals such as calcium carbonate and clay on the bottom of the tank.

One of the main reasons for the sediment deposition is the lack of maintenance on the heaters, mainly the lack of periodic drainage as recommended by manufacturers. Adding to this factor, many of the heaters that operate in dwelling units in Mexico City have overcome their lifespan established by manufacturers, which favors the formation of sediment.

The sediment layer formed at the bottom of the tank causes among other things the following effects.

a) Heat transfer from the flame and the metal surface to the water decreases because the sediment have low thermal conductivity and they act as insulation; so the liquid does not reach the proper temperature for the shower.

b) Corrosion inside of the tank due to reactions that can occur between certain components and metal.

c) Forming coat on the anode rod, which can cause it ceases to function properly and corrosion can appear elsewhere into the heater tank.

d) Damage to the lining of the tank, by explosions resulting from moisture trapped between the sediment stored. At saturation temperatures, the trapped water evaporates and expands, which occasionally can be detected when listening to explosions in the heaters.

Thus, the sediment accumulation at the bottom of the heater tank originates the device deterioration greatly decreasing their useful life. The thermal efficiency of this equipment is also lower with the passage of time, so that the energy required to operate the heater will increase.

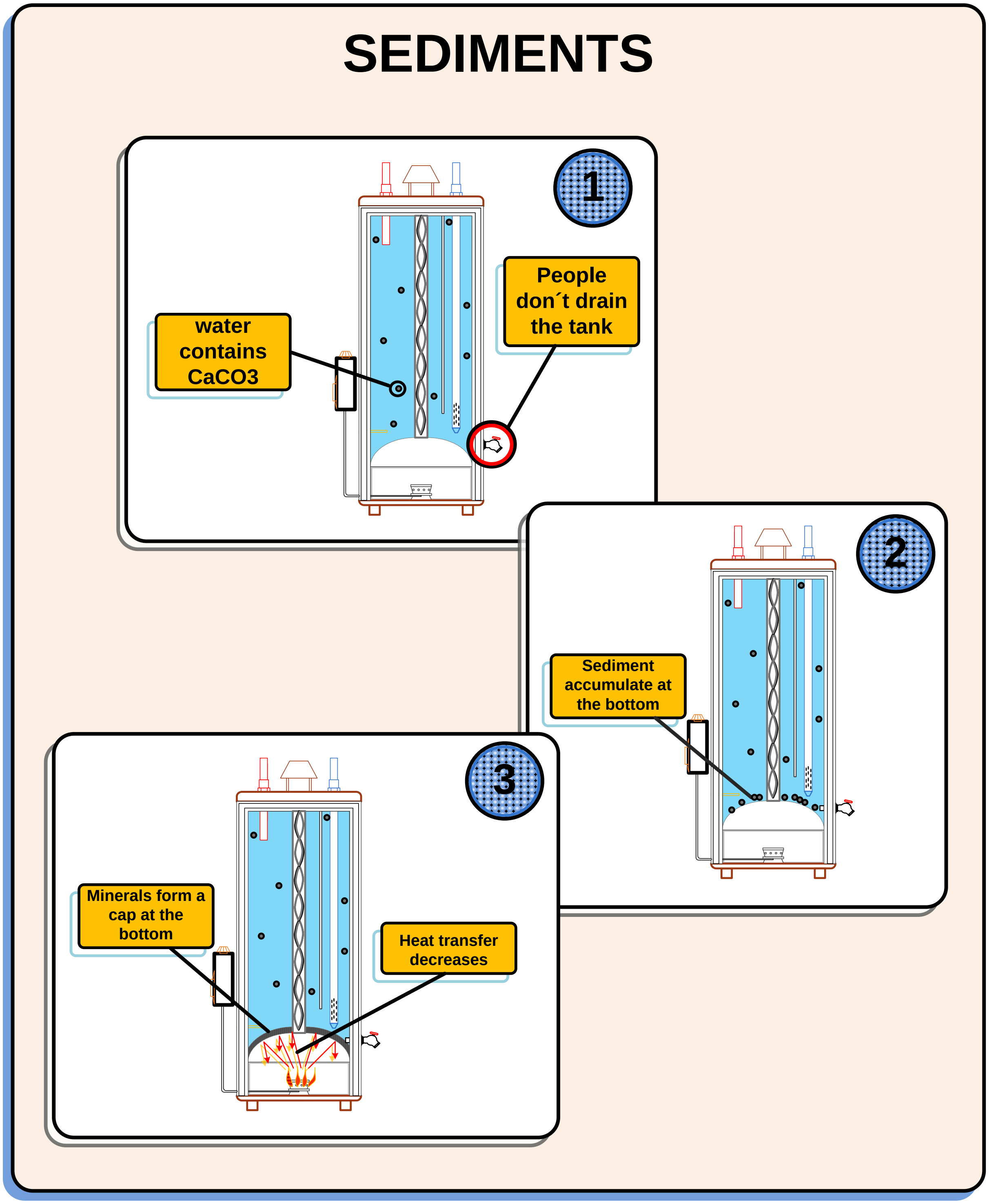
To perform a proper analysis of the efficiency losses of a tank heater due to the accumulation of minerals at the bottom of the tank, it would need to know a lot of factors such as:

• Chemical composition of water flowing into the heater to determine the type of sediment that may form, or directly a sediment chemical test.

• Thickness of the layer formed by sediment. The heater has to be opened for measuring it.

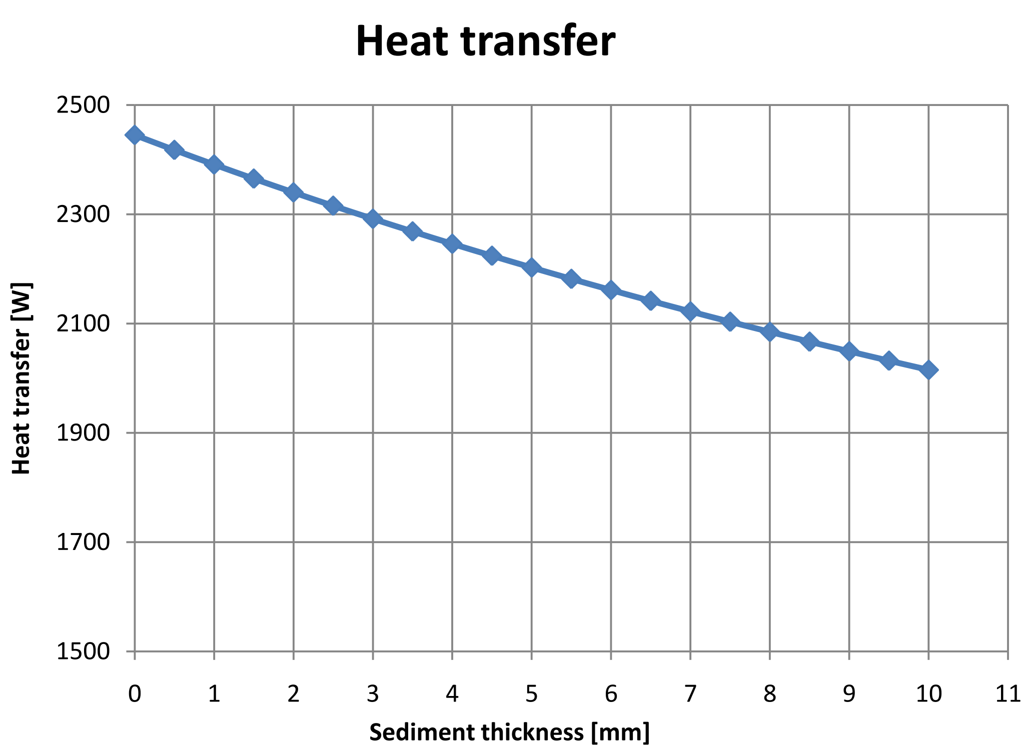
In addition, other variables are needed as the temperature resulted by fuel burning.

Sediment Formation in the storage water heater



To illustrate the effect of the sediment layer acting as a thermal insulator between the water and heat generated by the burners, it´s presented below in calculating the heat transfer from the gases generated during combustion to the water, varying the thickness sediment layer. Be clear, this exercise is only demonstrative, since it lacks sufficient information to generalize these data to all the heaters, but it is typical performance of similar equipment.

By varying the thickness of the layer of sediment, from 0.5 mm to 1 cm with intervals of 0.5 mm, we obtain the following graph of heat transfer (see Annex 4).



Heat transfer by varying sediment thickness

One can see that the heat transfer decreases proportionally with increasing thickness of the sediment layer, so this factor is a major obstacle in the smooth functioning of the heater.

Efficiency has the following behavior (see Annex 5):

Efficiency performance vs. sediment thickness at the bottom of water tank

Water heater efficiency has a very similar performance to the heat transfer, it varies directly with the thickness of the layer of sediment, having an inch thick, heaters have an efficiency of 60%.

It´s shown that a accumulated sediment layer at the bottom of water tank storage heater, which is very common problem in most of the heaters, greatly affects the thermal efficiency of the system at values far below the original.

Corrosion

Corrosion is the deterioration of a substance or its properties due to a reaction with its environment. For internal corrosion, the environment of concern is water.. There are several characteristics that determine the level of corrosion that can occur in any metal, they can be classified into three types, physical, chemical and biological. Within the physical factors is water velocity and temperature. Among the chemicals factors are the fluid pH, CO2 levels and alkalinity. Finally, the biological factors include both anaerobic and aerobic bacteria.

Flow velocity has seemingly contradictory effects. In water with protective properties, high flow velocities can aid in the formation of protective coatings. However, high velocity waters combined with other corrosive characteristics can deteriorate materials.

Temperature effects are complex and depend on the water chemistry and type of construction material. In general, the rate of all chemical reactions, including corrosion reactions, increases with increased temperature. Also, less CaCO3 dissolves at higher temperatures. Finally, temperature can change the nature of the corrosion.

There are several chemical characteristics related to corrosion tendency. Some of them are the following:

- PH, low pH may increase corrosion rate; high pH may protect materials and decrease corrosion rate.
- Alkalinity, May help form protective CaCO3 coating, helps control pH changes and reduces corrosion.
- Oxygen, increases rate of many corrosion reactions
- Chlorine residual, increases metallic corrosion
- TDS (total dissolved solids) High TDS increases conductivity and corrosion rate.

- Hardness (Ca and Mg) Ca may precipitate as $CaCO_3$ and thus provide protection and reduce corrosion rates.
- Chloride, sulfate: high levels increase corrosion of iron, copper and galvanized steel.
- Hydrogen sulfide: Increases corrosion rates
- Silicate, phosphates: May form protective films.
- Natural color, organic matter: may decrease corrosion
- Iron, zinc, manganese: may react with compounds on interior of A_C pipe to form protective coating.

The corrosion process in the storage water heaters can be given for several reasons; among the most common are the following:

Corrosion Caused by Softened Water

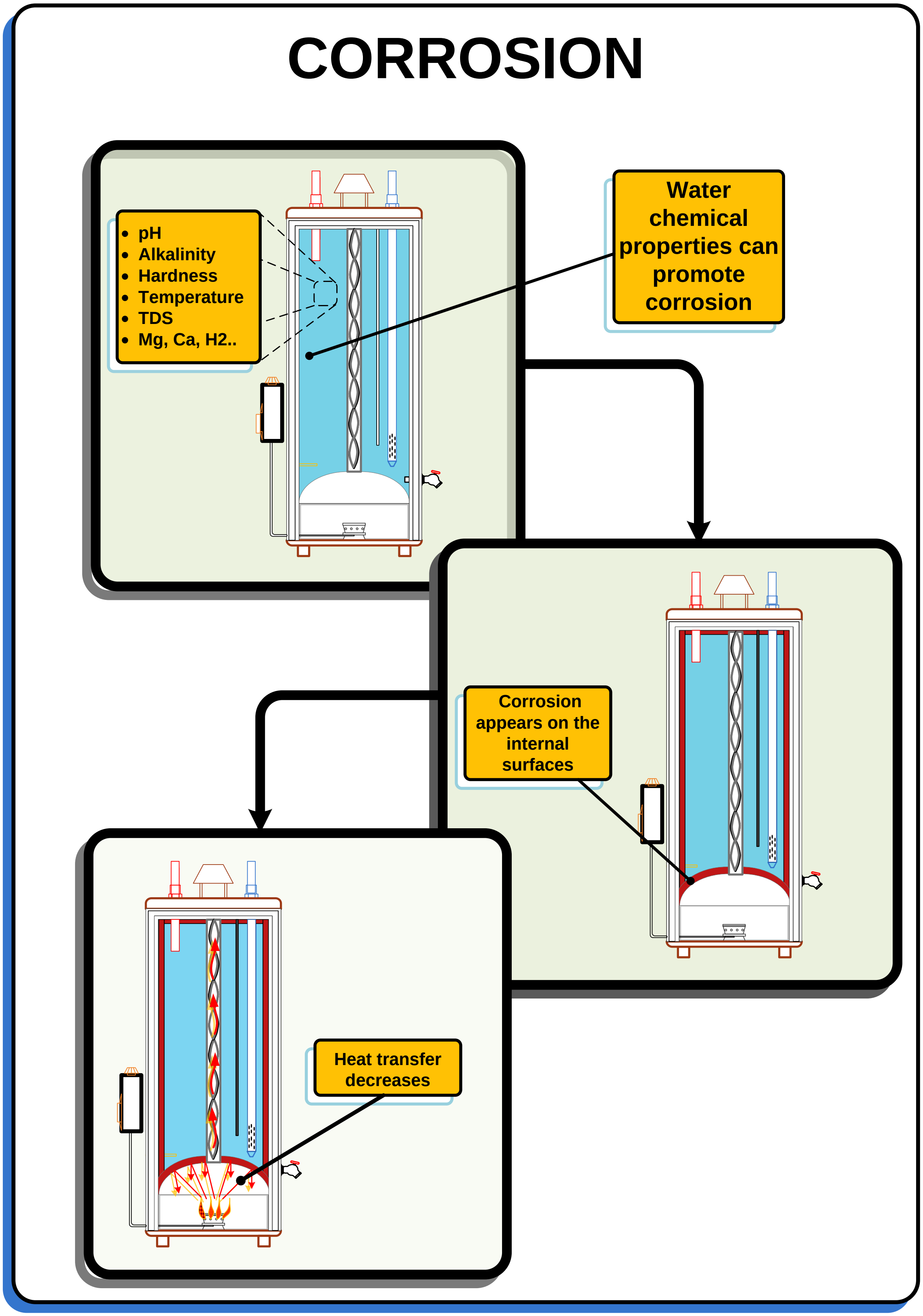
The Softened Water removes or chemically reacts with other minerals to make them inert. The most common water softening agent is salt, which can often be more corrosive than other minerals and consume anode rods faster than the minerals found in hard water.

Corrosion Damage in Anticorrosion rod

This rod is essential for long-term health of the water heater. The bar corrosion prevents corrosion of the rest of the water heater at the expense of sacrificing the metal within the rod. In essence, if successful, the anode rod corrodes instead of the water tank. Sometimes, anode rods can be covered by a very hard layer of calcium carbonate. This will prevent the bar to do its work because the layer will prevent the dissolved ions can react with the anode rod and the water heater will begin to corrode. The only way to know if an anode bar is covered by calcium carbonate is to uninstall the rod and try to bend it. If it bends easily then the anode rod is no longer useful.

There are many methodologies to diagnose levels of corrosion, such as assessing water pH, sampling and chemical analysis or examination of water pipes as well as measures to counter the deterioration of equipment and balancing the pH, or water softening; without But these measures are mainly directed to sources of water supply, so that on the way in the distribution system, water can modify its properties. For this reason, it is very common for storage water heaters which are used by the majority of the population, have presence of corrosion in varying degrees.

Corrosion forming on the inner walls of a storage heater



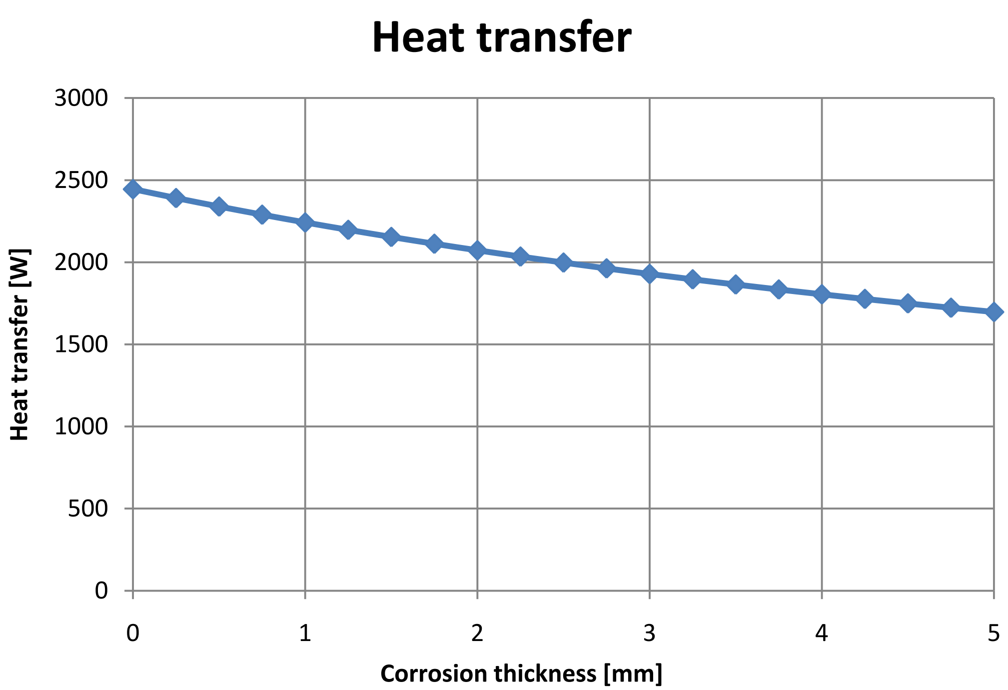
Consequences

a) Reduce the heat transfer between the burner flame and the water in the tank.

b) Water spilling can generate bites, causing hot water loss and therefore energy. Furthermore, the water that spills, promotes the formation of corrosion on external surfaces.

Unfortunately, it is very difficult to determine the amount of corrosion present in all the heaters, because the factors are many and vary in every heater, not excluding the difficulty of spot measurements in each household. However, the following example illustrates the scale of the problem. The corrosion acts as insulation that affects heat transfer.

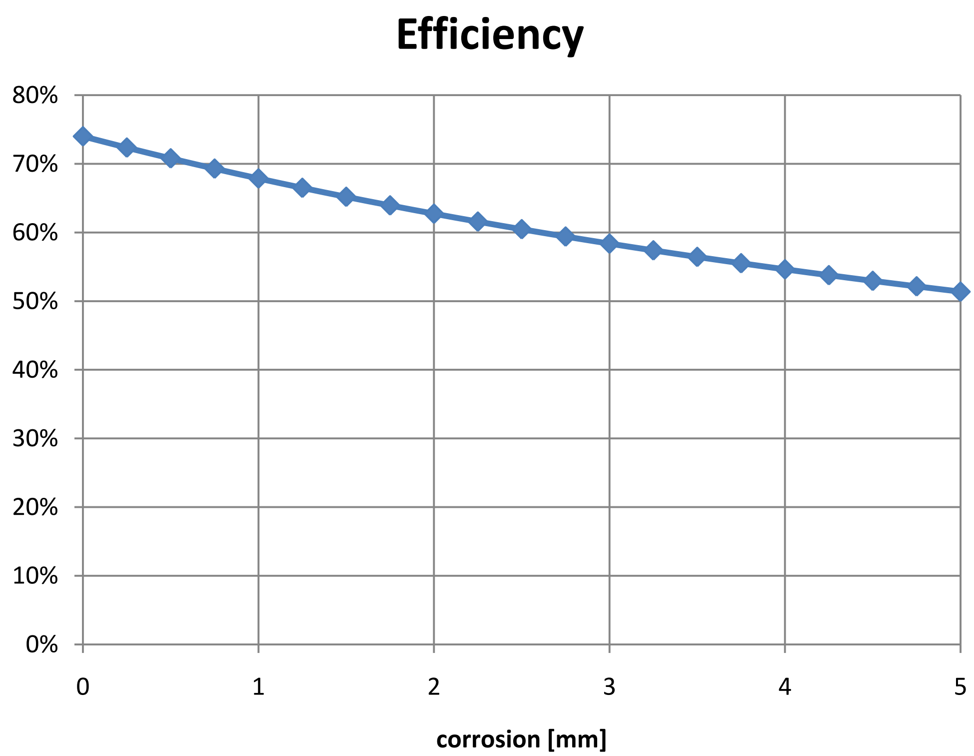
The results obtained by placing a layer of corrosion whose thermal conductivity is lower than the original layer of the tank, are illustrated in the following chart (see Annex 5):



Heat transfer performance according to the corrosión thickness

We can conclude that if there's a corrosion layer on the internal surface of the heater, heat transfer between the burner flame and the water, significantly decreases with increasing thickness of the layer.

Following this assignment, the overall thermal efficiency of the heater decreases at the same rate, as illustrated in the following chart (see Annex 6):



Thermal Efficiency with respect to corrosion layer Thickness

BURNERS IMPAIRMENT LOSS FACTOR

The burner is the key component of any application of gas. Its mission is to achieve complete combustion and a correct gas-air mixture, generating a stable and consistent flame and adapting the heat emission to heat the product.
One of the most common problems in gas burning water heaters is the presence of soot on the burners, causing bad combustion, that means, part of the fuel remains unburned or in many cases the flame does not reach the proper temperature for heating water.

There are indicators that can help detect this problem, as the color of the flame, which becomes yellowish or simply the declining quality of hot water. Among the main reasons for this common problem are:

- Presence of scales on the top of the burner
- Restriction of inlets or gas in the tube
- Do not supply enough air to ventilate the instalation

These factors may be aggravated by poor maintenance of the burners or by operating under different conditions than the design without prior adaptation, as is the case of burners designed to operate with Natural Gas using LP Gas. Some problems can be solved without calling to a technical expert, but in many cases is indispensable help of a skilled attendant that generates a maintenance cost and most people avoid these services, factor that contributes to equipment deterioration.

Burners are distributed in different ways depending on the aspect analyzed:

- Depending on the shape of the heat transfer to the load. We distinguish blue flame burners (heat transfer by convection) and radiant burners (transmission of radiant heat as possible).

- Depending on how they get the air-gas mixture. They differ partial mix burners (primary air mixed with gas above the burner and secondary air sucked into the flame) and premix burners (with all the air mixed with gas before reaching the burner).

- According to the mechanical draft that ensures the air into the burner. Atmospheric burners are distinguished (with input from the air by natural draft) and with fan-assisted burners (with aspirated or forced draft).

The storage water heaters regularly have blue flame burners, for transmitting large amounts of heat by convection, are pre-mixed and natural draft burners. The general characteristics of this type of burner are:

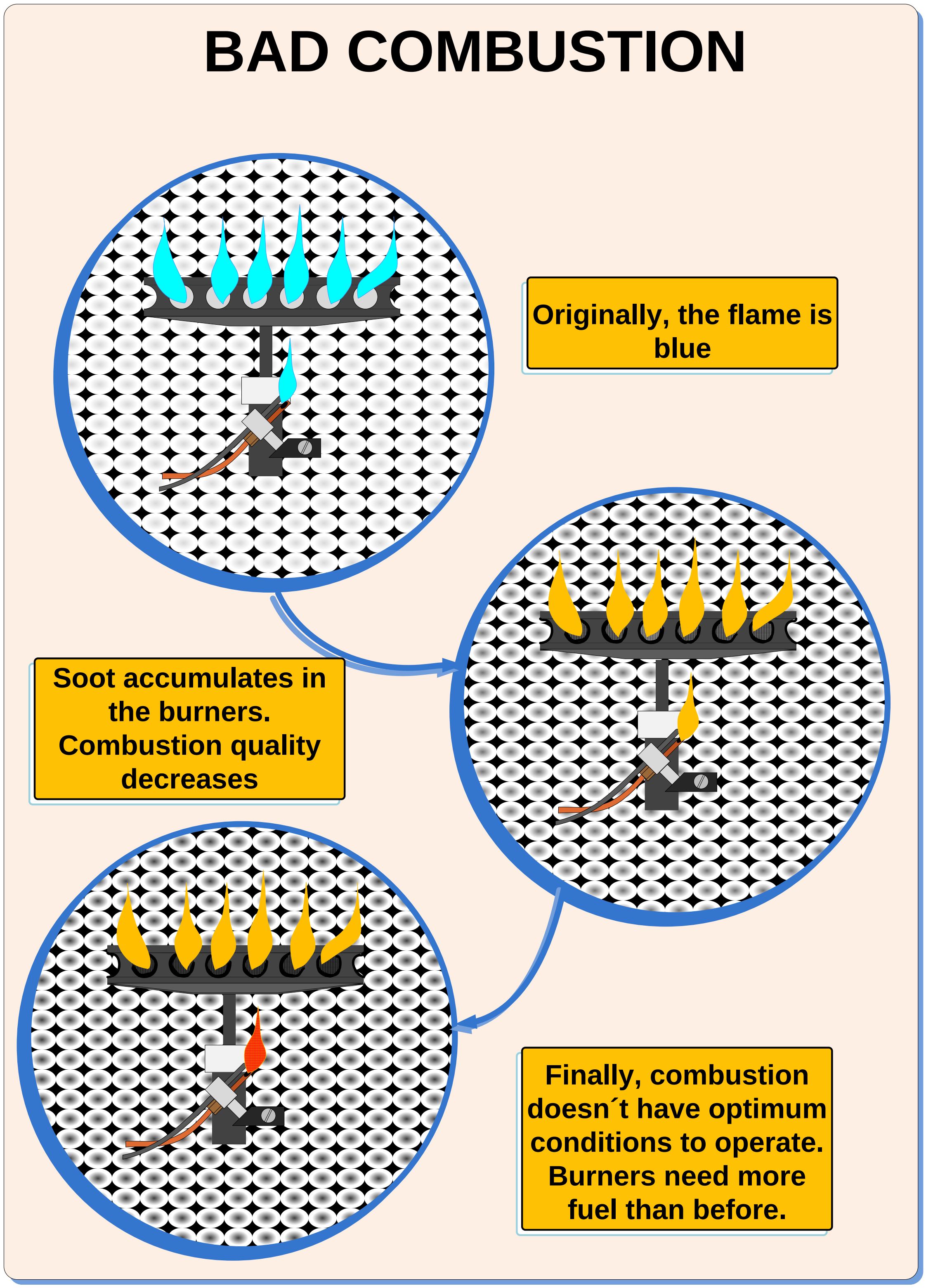
- Uniform distribution of the flame (and uniform height) with uniform distribution and efficient heat the heating element (water heat exchanger , cooking oven, etc.).

- Complete gas combustion, with minimum emissions and always meet current regulations.

- Stability of the flame, without evolution or decline of the same throughout the power range of the burner.

- Long life burner (12 to 15 years), similar to that expected for the application in which it is installed, and no appreciable degradation over its useful life.

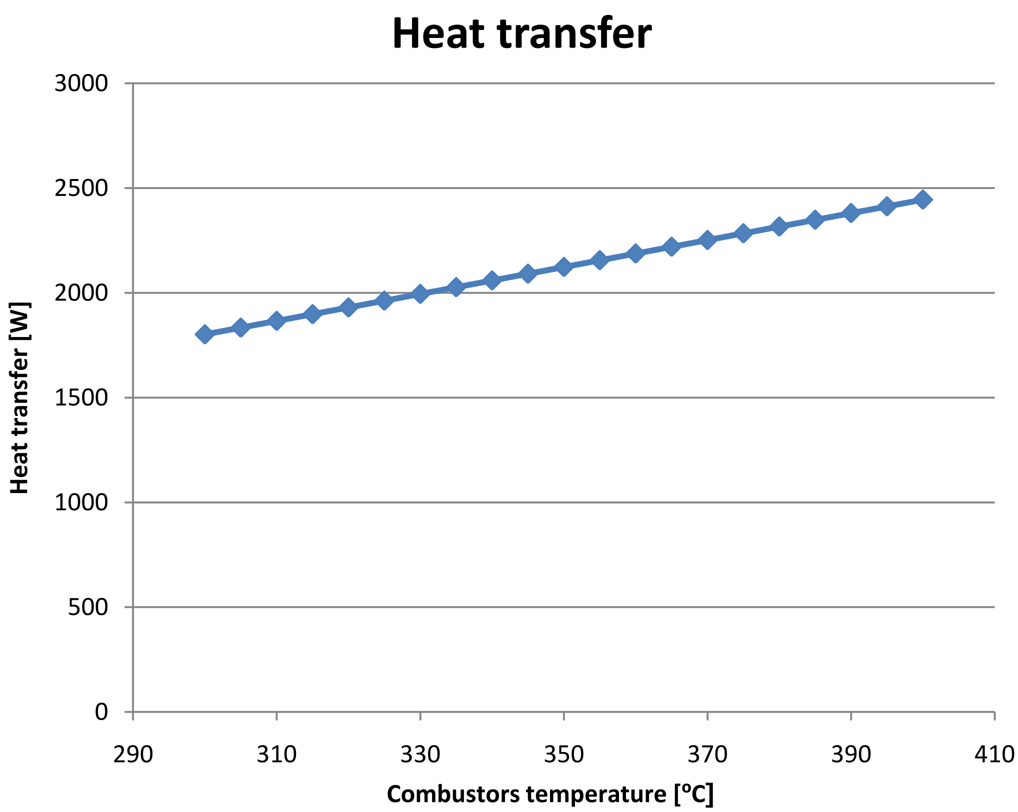
Deterioration process in Burners



Consequences

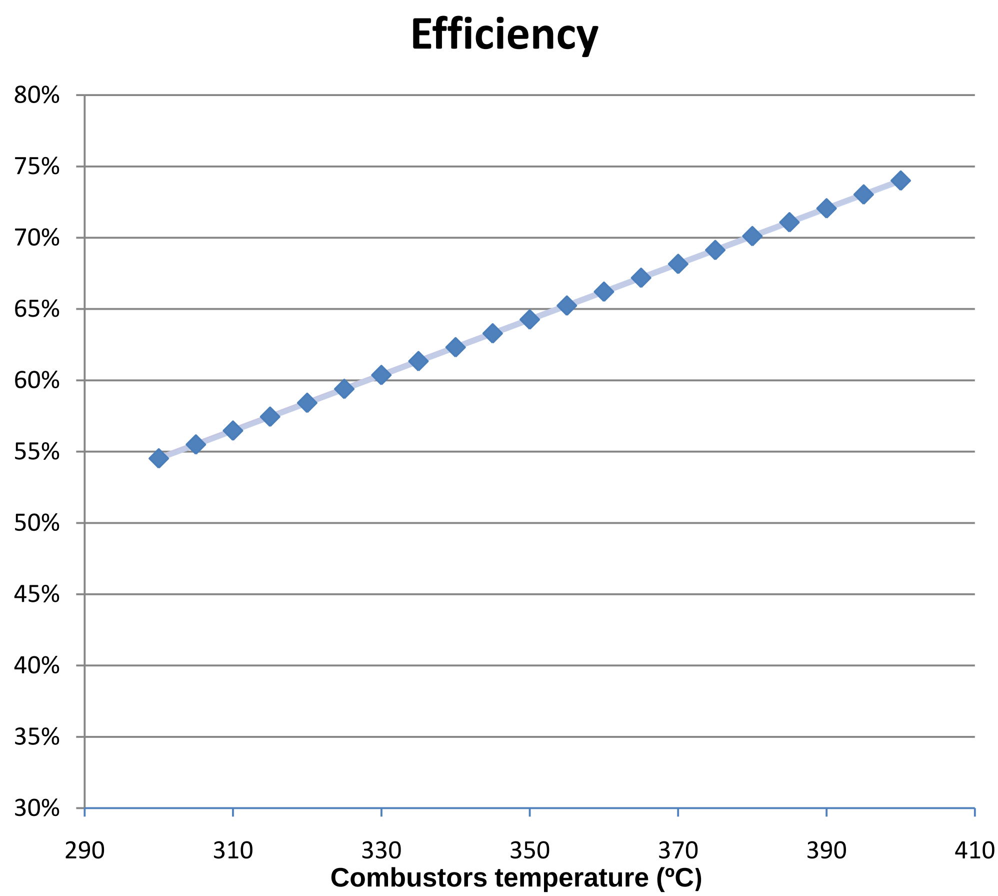
One of the main effects of poor combustion is the decline of the temperature rise in the burners flame, this decline also affects the temperature generated in the combustion chamber and therefore the energy available for heating water through heat exchange is lower.

To give idea of how it affects the temperature of the flame, next graph illustrates the energy exchanged depending on the available temperature by gas combustion.



Heat transfer performance as a function of temperature

Following the decrease of heat transfer decreases in the temperature achieved in the burners, heater thermal efficiency also decreases



Thermal efficiency performance as a function of combustors temperature

It is advisable therefore, to maintain the best possible conditions the burners, since the damage of these equipments greatly impact the overall efficiency of the heater.

HEAT TRANSFER LOSS FACTOR AT FLUE GAS PIPE

In storage heaters, as the energy supplied by the fuel is used for water heating, the combustion gases are utilized in the exhaust pipe for the same purpose, of course, the ratio is several times lower in magnitude.

The exhaust gas system for storage heaters which are the subject of Faulkner Project study, generally have the following elements:

1. *Deflector*. Device responsible for generating turbulence in the combustion gases, along with promoting a greater residence time to improve heat transfer between gas and water heater.

2. *Ventilation hood*. Its function is to blur the flue gas at the end of the exhaust pipe.

3. *Flue*. Device responsible for conducting the exhaust gases to the atmosphere and improve the efficiency of the heater, taking advantage of the residual energy of hot combustion gases during their travel through the tube.

The flue gas pipe is exposed on its interior, of exhaust gases, and outside, by the water in the heater. The gases are at an average temperature between 200-300 º C during its travel through the tube, while the water between 25-50 º C during the heating process.

On both sides of pipe, exterior and interior, thermal properties may be lost due to the formation of chemicals compounds that reduce the efficiency of heat transfer between combustion gases and water within the heater; mainly corrosive chemicals.

Inefficiencies caused by water in heater

As mentioned earlier, the interior walls of the heaters are susceptible to corrosion and encrustation of calcium carbonates. The flue gas pipe is not exempt, because it may be affected by these chemicals phenomena. However, corrosion is the main factor that causes inefficiencies inside the heater, for lack of maintenance on the heater's anode rod.

Corrosion affects the efficiency of heat transfer between exhaust gases and water within the heater, and hence the overall efficiency of the heater.

To quantify the magnitude of the impact of this factor is very complicated; however it is possible to estimate how behaves the heat transfer efficiency with this phenomenon.

Inefficiencies caused by the combustion gases

In reverse, we have the inside wall of the gas tube. Here is where the flue gas flows at high temperatures, allow heat transfer to the water inside the heater.

To make the fuel combustion is required the presence of oxygen. The fuel, which can be natural gas or LP, has as main elements carbon and hydrogen while the air is composed mostly of nitrogen, oxygen and water steam (humidity).

LP Gas	Formula	% C	% H
Propane (60% max)	C_3H_8	81.81	18.19
Butane (40% max)	C_4H_{10}	82.76	17.24
Ethane (2.5% max)	C_2H_6	80	20

LP gas composition

Natural Gas	Formula	% C	% H	% N	% O
Methane (83-84% min)	CH_6	75	25	0	0
Ethane (11% max)	C_2H_6	80	20	0	0
Carbono bioxide (3% max)	CO_2	27.3	0	0	72.7
Nitrogen (4-5% max)	N_2	0	0	100	0
Oxigen (.2% max)	O_2	0	0	0	100

Natural gas composition

As discussed in the section on combustion, when the hydrogen of the fuel reacts with oxygen in the air, they produce water steam.

From the general equation of combustion for LP and Natural Gas, we see that in the right side of this equation there is the water formation (H_20), in gaseous form:

$$C_xH_y + n_1(O_2 + N_2) \to xCO_2 + \left(\frac{y}{2}\right)H_2O + 0.21(n_1 - n)O_2 + 0.79n_1N_2$$

Moreover, the gas tube is composed of carbon steel, a material composed mostly of the element Iron. The Iron, in presence of water steam and oxygen can promote the electrochemical process; corrosion.

The corrosion produces iron oxides or *Herrumbre*, which has a higher heat resistance than iron, which reduces heat transfer efficiency.

Corrosion Impact

Corrosion reduces the efficiency of heat transfer in this part of the heater, fortunately not so aggravating, but coupled with a list of factors that similarly reduce efficiency, becomes important.

Moreover, the thermal conductivity is an intensive property of material (not dependent on the amount of material), while greater is it value, better is the heat transfer. The average thermal conductivity of the flue gas pipe is 50 W/m^2*K while the rust or iron oxide (Fe_2O_3), ranges from .005 to 5 W/m^2*K. The difference between the two causes the heater to operate not at optimal conditions (design), which directly impacts efficiency.

The efficiency losses between a new and old heater, can be demonstrate with an increase in temperature of exhaust gas, due to a decline in the use of energy.

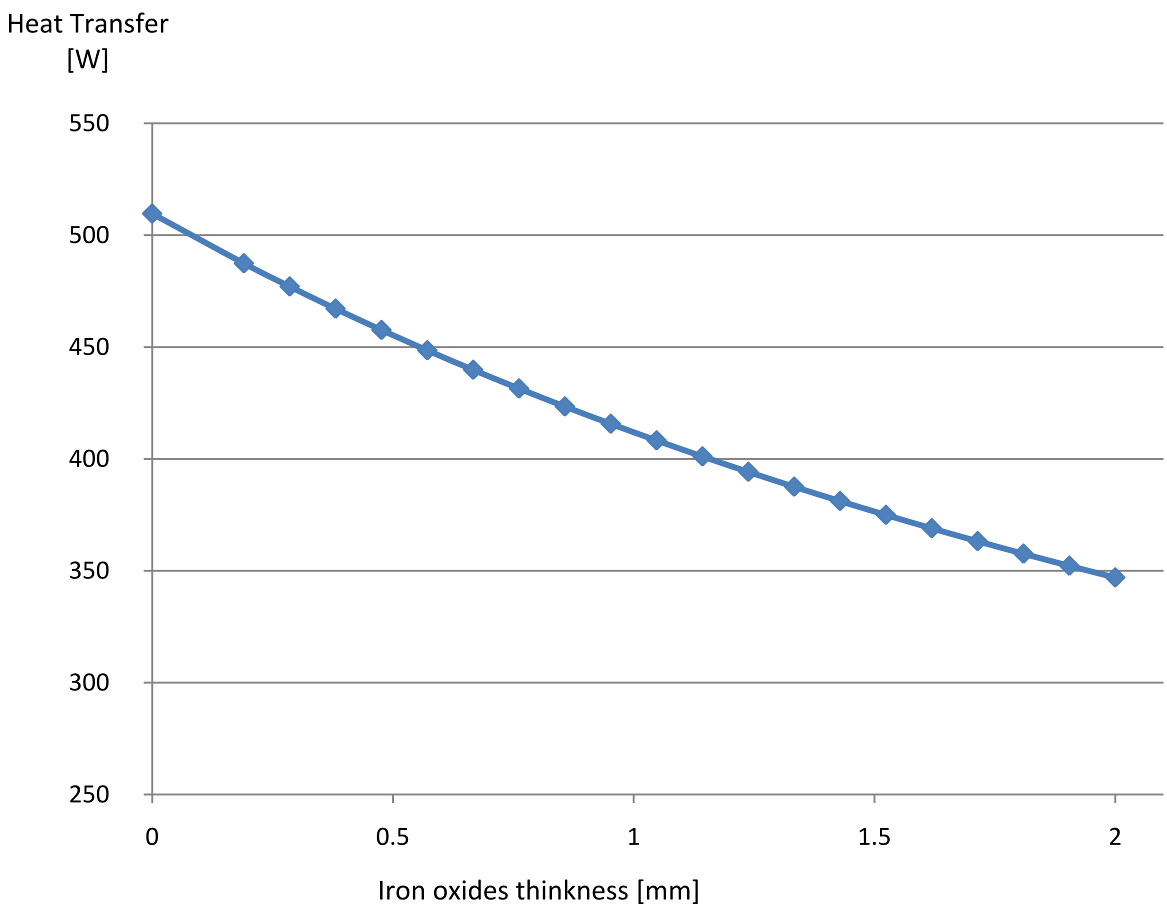
In order to illustrate the impact of the loss of heat transfer by the formation of ferrous oxide in the gas tube walls, we used information from one study of AIMEX.

The study that were the basis for the following example corresponds to the residential house located at *11 Avenue, No. 62, Block 1, House number 23, Colony Star Farms, Unit Housing "State of Anahuac," Iztapalapa, Mexico DF.*

The information taken from AIMEX study was as follows:

- Storage Capacity, 38 Liters
- Outlet gas temperature 228 ° C
- Flue gas flow, 131 kg / h
- Pipe diameter, 0.08 meters
- Flue gas pipe length, 0.7 meters
- Gas manometric pressure at the exit of the gas pipe, 0.119 in H2O

The following chart shows the heat transfer losses when there is a uniform film of thermal insulation thickness (iron oxides), from zero to 2 millimeters.

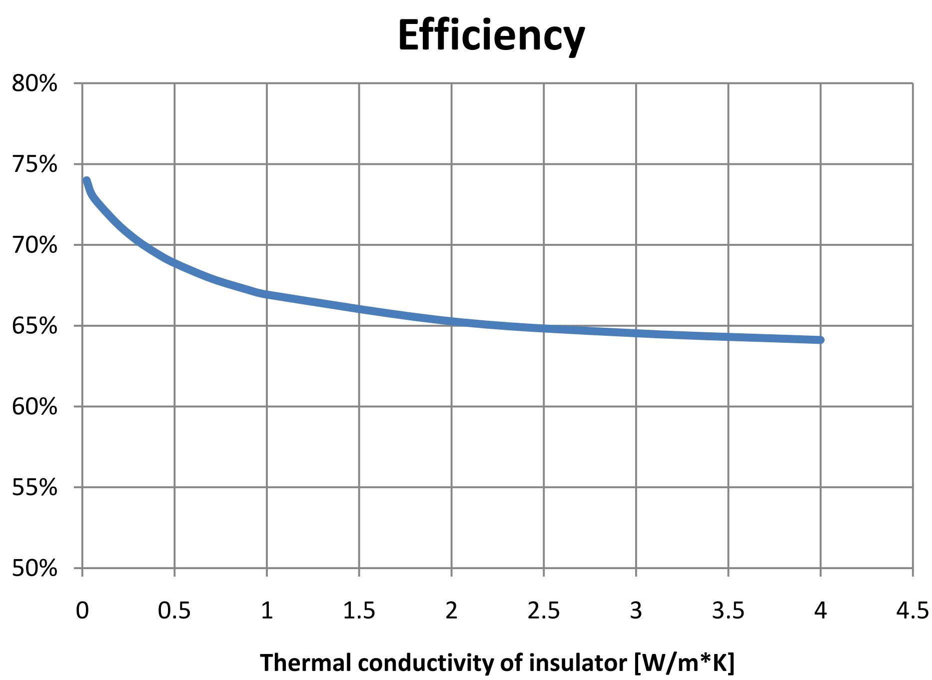


Heat transfer performance as a function of iron corrosion in pipe gases

As can be seen, the energy decreases as the iron oxide layer increases, its behavior is logarithmic; asymptotic to the axis of thickness. To develop it, was necessary to study the convection heat transfer between flue gas and water pipe gases, and conduction between the tube material and iron oxides. The basic considerations used to make the graphic content are presented in Annex 6.

INSULATION IMPAIRMENT LOSS FACTOR

Another problem that may occur in storage water heaters is the deterioration of the insulating layer surrounding the water tank. Regularly consists of polyurethane foam, which although highly water resistant, it can become damaged and lose its thermal properties, thus the water heats the environment and therefore the system would be less efficient.



Efficiency losses by insulation impairment.

The results indicate that heat losses and hence overall water heater efficiency for damage suffered by an insulator along its useful life are few, however in the worst case, increasing the material heat conductivity up to 4 W / m * K, an event that would be very complicated in reality, the original efficiency of 74% would decrease to 64% (See Annex 7).

INTERNAL CORRECTION FACTORS FOR INSTANTANEOUS WATER HEATERS

These heaters have two mainly internal factors that affect its efficiency: the damage in burners and the calcium carbonate fouling at the pipelines. Unlike storage heater, corrosion is not a serious problem because the pipe through which hot water flows is composed of copper; a material resistant to corrosion. Also the degradation of insulation is not a major problem due to the nature of heat transfer phenomenon in this type of heaters.

The operation of instantaneous heaters is similar as the automobile radiator: the copper pipe is interwoven through the outside with aluminum fins forming a rectangular block. The fins improve heat transfer efficiency. Then, when the burners are lit, the hot combustion gases are distributed uniformly across the rectangular block. It is known as a heat exchanger.

Instantaneous heaters, as well as storage, require periodic maintenance to correct any imperfections that may affect the life of the equipment. The location of the heater can also affect its efficiency, mainly because of the combustion process. It must be taken special care to the access of combustion air and the outlet for exhaust gases, the inefficient combustion affects the overall efficiency of the heater.
In the rest of the document appear the details of the effects caused by these two main factors that affect the efficiency of the instantaneous heaters.

CORRECTION FACTOR FOR DAMAGE IN BURNERS

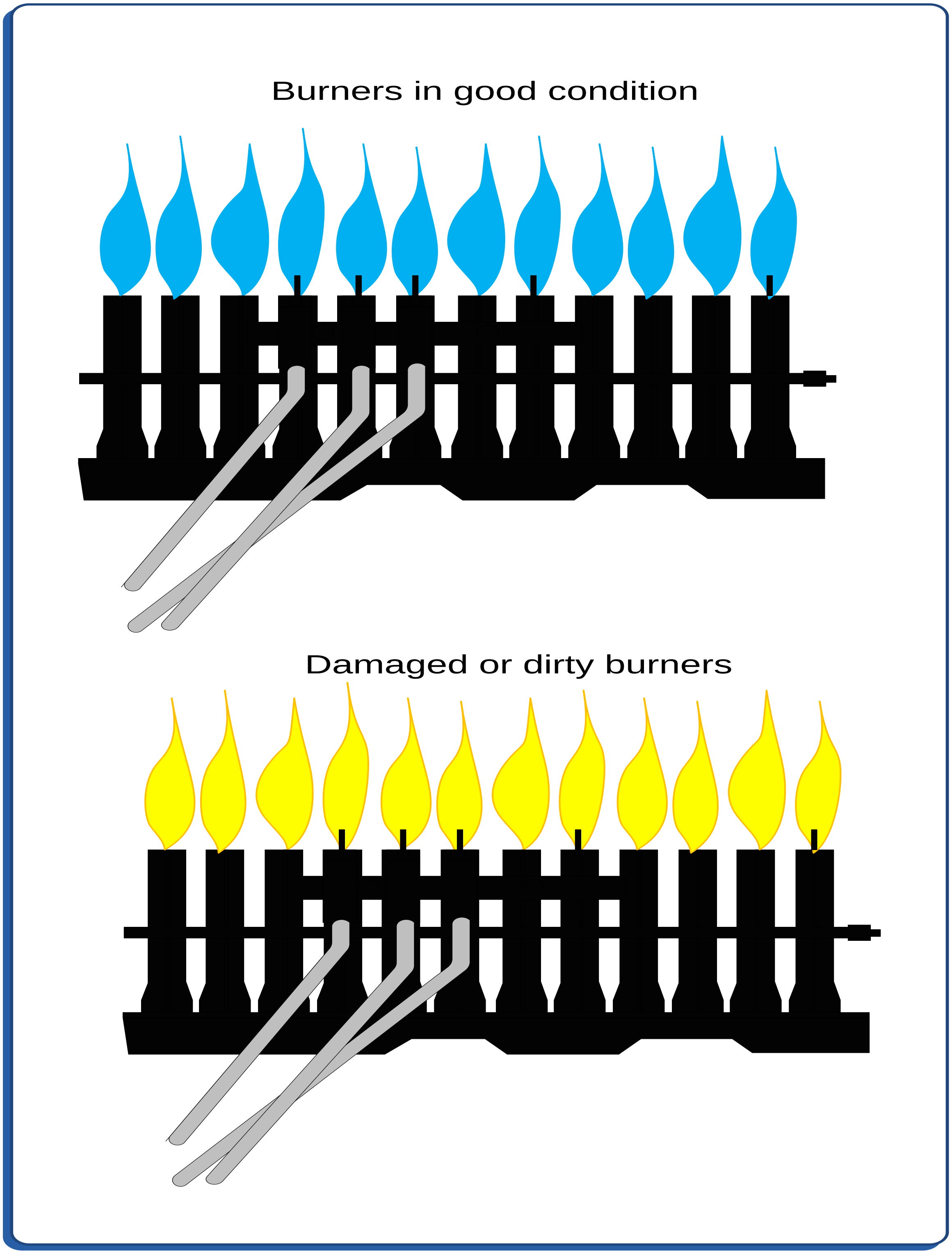
As in a storage heater, it is very common to have problems in instantaneous heaters due to bad operation of the burners. The most common reason is the obstruction of the combustion openings and/or air inlets.

The burner flames are blue initially, with a more intense blue cone in the center. If flames are yellow may be a sign that the size of the openings is not the correct one. That means that the burners are dirty, or that the heat exchanger fins are blocked. If there are dirty, one of the most common problems is the presence of soot in the burners causing bad combustion, another possibility is that the Venturi of burners is partially clogged by dust, lint or spider webs.

The lack of maintenance of burners, affect the quality of hot water. This happens because the flame temperature decreases so the energy transferred to water is reduced. Also the heater's thermal efficiency is lower in these conditions.

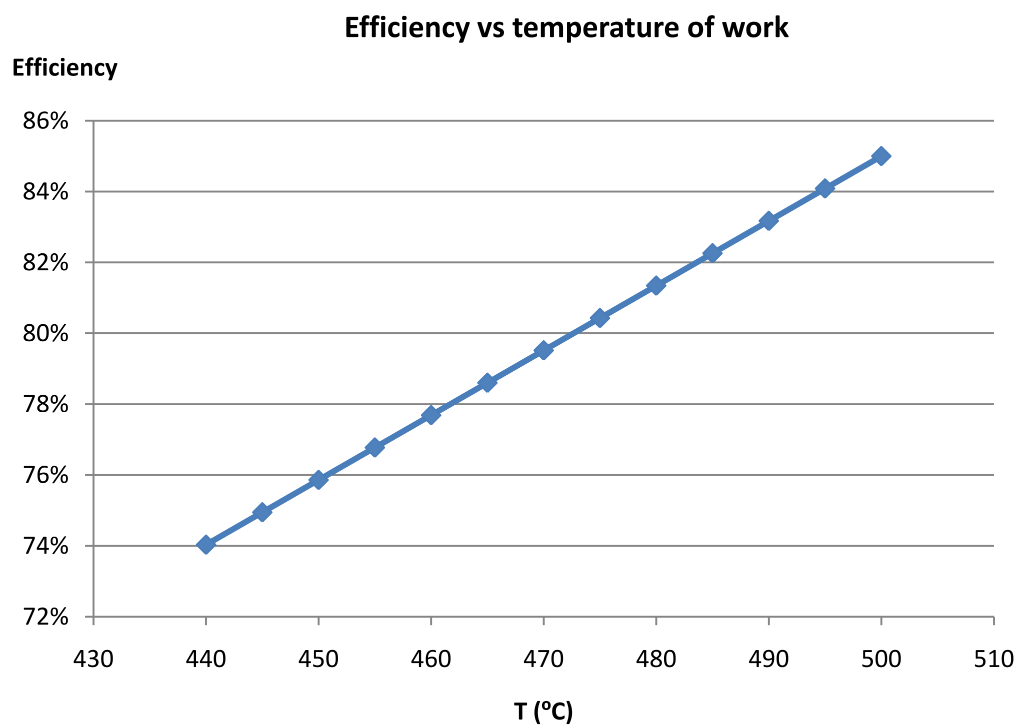
In housing, maintenance to burners is generally not given, so you may have a bad combustion process, with an orange flame or yellow color. When this happens, the burner is not operating at design conditions (maximum efficiency), that creates losses into burners and in heat transfer; hence the heater requires more fuel to achieve the same increase of temperature.

Deterioration process in Burners



Consequences

In order to illustrate how does the efficiency of a heater behaves when the temperature of the flame decreases, the following chart is presented.



Thermal efficiency performance according to temperature generated by instantaneous water heater burners.

The results show that as the flame temperature decreases 10 Celsius, the efficiency is reduced by two percentage points; in gross numbers.

To develop the above chart, the heat transfer by conduction and convection in this type of heat exchangers was studied.

HEAT TRANSFER LOSS FACTOR IN COIL PIPE

Instantaneous heaters are designed with certain quality standards that ensure the efficiency of these; however, in most cases these design conditions are often violated. One of the main loss factors in the heater efficiency is due to the calcium carbonate fouling in the pipeline (heat transfer area). The main agents for this fouling are the dissolved impurities in the supply water.

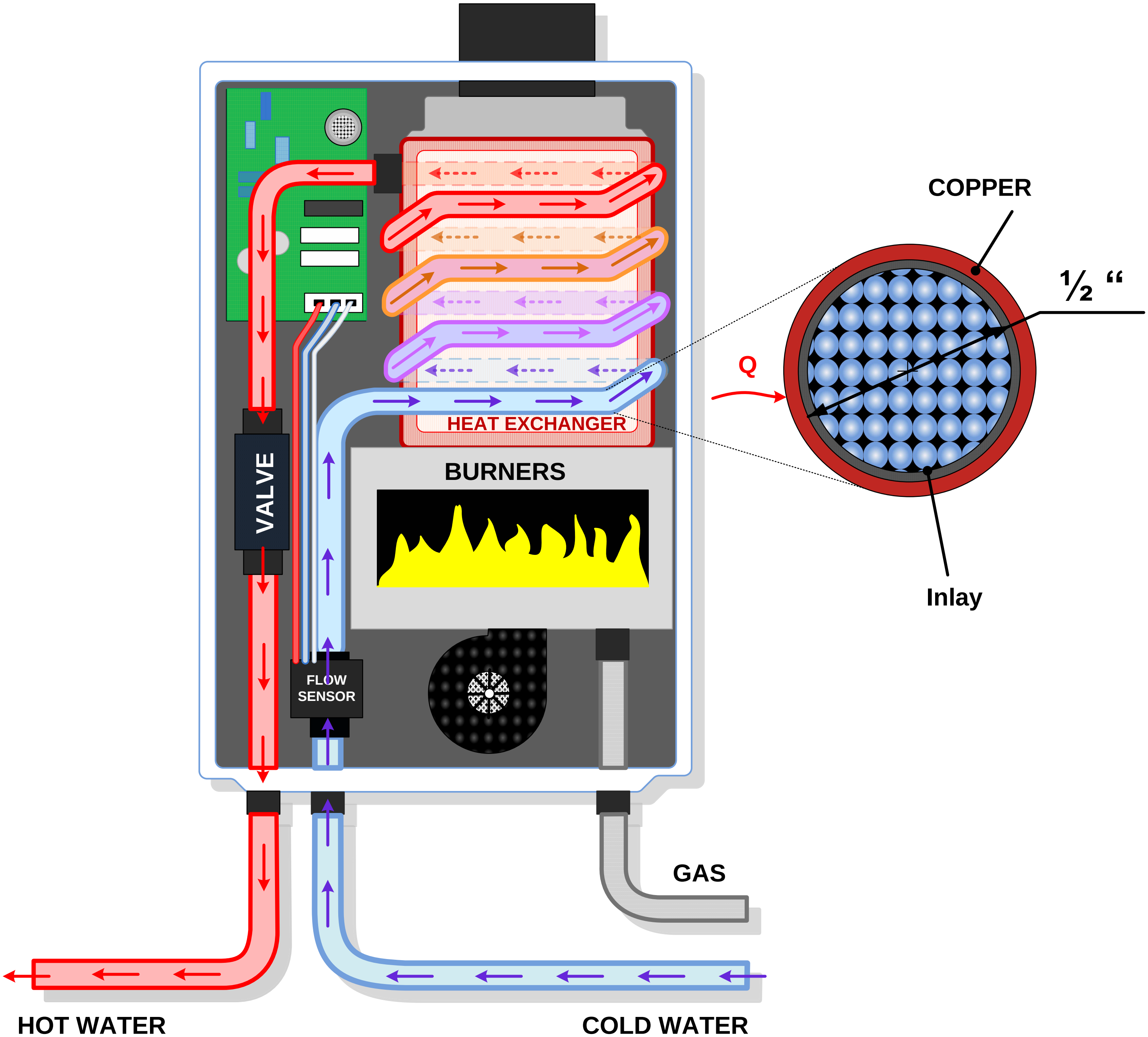
The inlay subtracts efficiency of heat transfer process because it forms a wall on the inner surface of the pipe, which is the area of heat transfer. While the thickness of inlay grows the thermal transfer will be lost, in other words, more heat is needed to transfer the same energy that is transferred without inlay. Besides having a material addition, the inlay does not possess the same characteristics of the heater pipes, and generally, the coefficient of heat transfer (thermal conductivity) is lower, reflecting greater resistance to transfer energy from the flame to the heat water.

If the heater is used in high temperatures and the water has a high mineral content, may need regular descaling. The coil pipe should be flushed with a descaling solution. The descaling is done only in the heat exchanger.[6]

The following image illustrates the operation of the instantaneous heater, and how the thickness of inlay in the pipe reduces the efficiency and increases the resistance to the heat transfer.

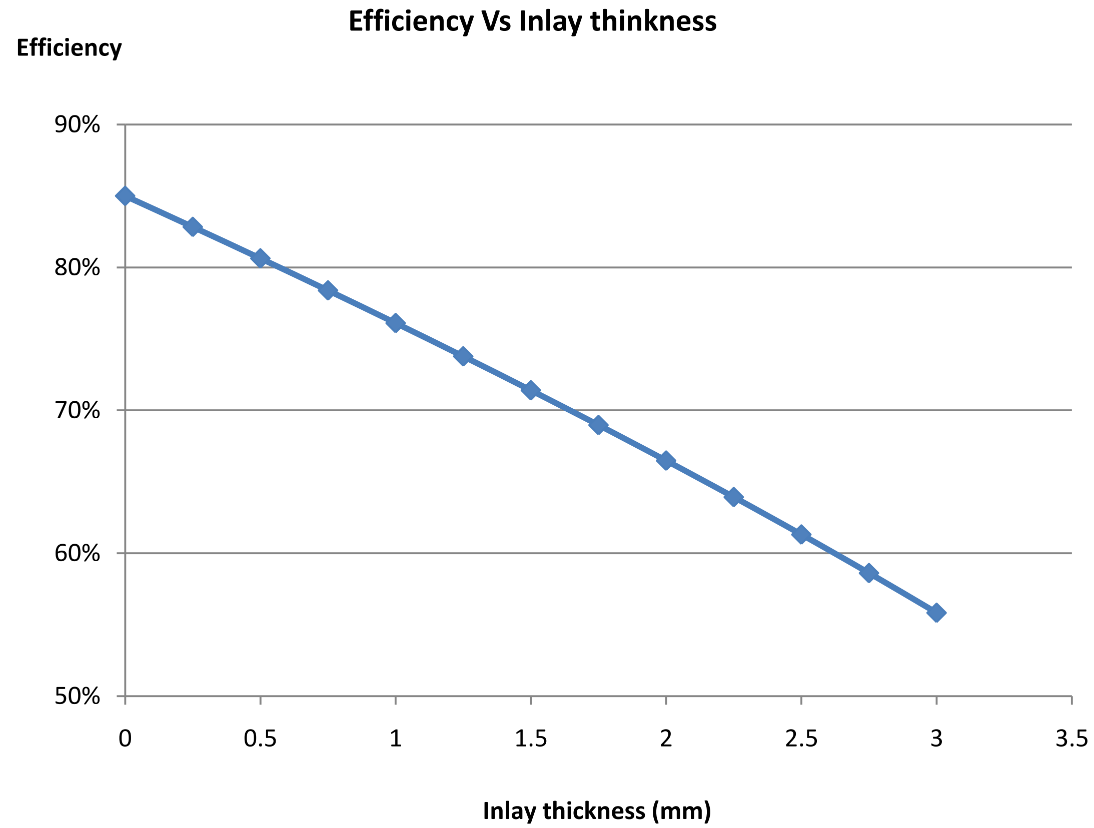
[6] Manual de instalación y manejo para calentadores instantáneos de agua a gas natural o G.L.P. BOSCH 2006

Parts that make up and operation of the instantaneous heaters



Consequences

The graph below shows how the heater efficiency behaves. It shows an analysis of heat transfer change, varying the calcium carbonate inlay thickness in millimeters into a 1/2 inch copper pipe for the heater.



Thermal efficiency as a function of inlay thickness in an instantaneous water heater

For every half of a millimeter of thickness in calcium carbonate inlay, the heater loses about 4 percentage points in its efficiency.

LOSS OF ENERGY IN HOT WATER SUPPLY SYSTEMS

The following points are factors not involved in the efficiency of water heaters, but they represent an energy loss in the pipes during the operation of the heater and even when it is not operating.
To the Faulkner Project these energy losses represent a business opportunity as it involves burning more fuel, resulting in more CO2 emissions. These factors are applicable for houses equipped with instantaneous and storage heaters

COLD WATER TEMPERATURE

The temperature of supply water (cold water) is an important factor that affects the increase in the CO_2 emissions in the heater. This affects because if the temperature of the water is very low, the consumption of fuel to heat this water will increase. This will depend primarily on the site weather conditions; generally the supply water temperature is less than the site temperature. In the housings from Project Faulkner, weather conditions correspond to those of Mexico City, the temperature ranges between 6°C to 26°C during the year.

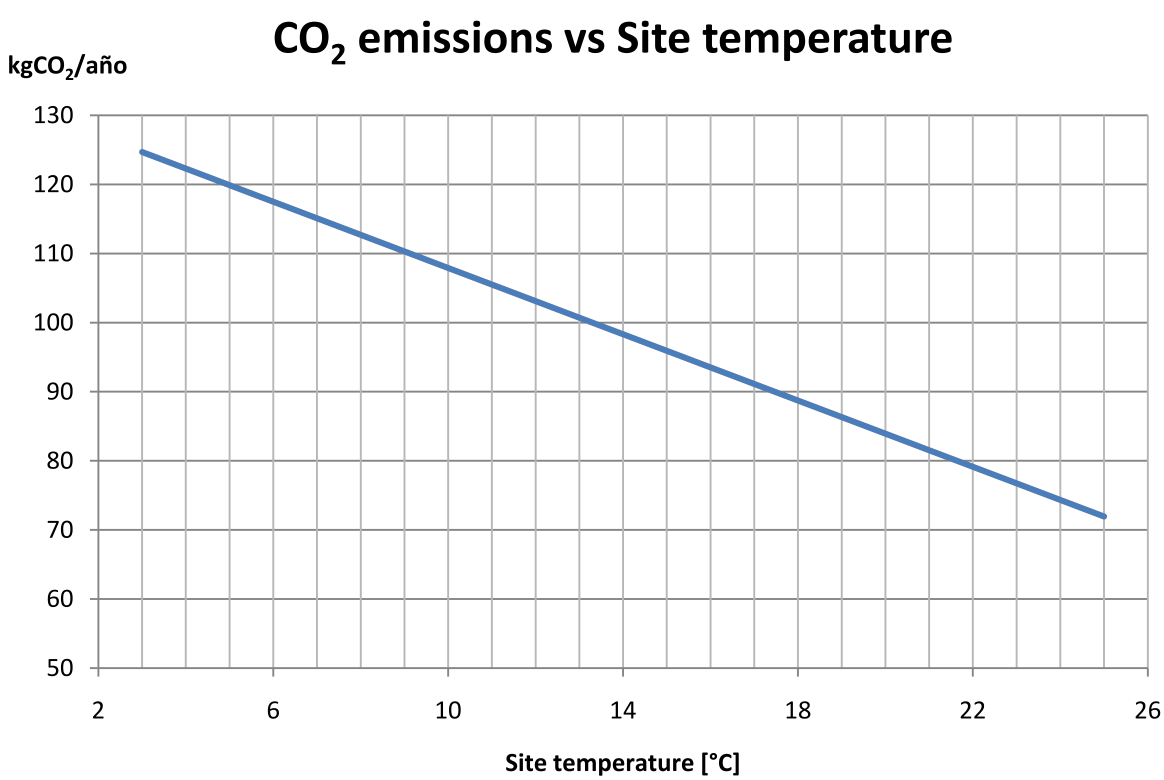
The average temperature that has been used for the evaluation of this project is 15 C. This temperature is used conservatively, since the temperatures that should be taken into account, are the ones in the morning and after dusk. This because in Mexico City, most people usually take showers in the morning (before starting the work day) or evening (before sleep). The temperature at these hours is lower than 15°C.

Moreover, it is important to know that the water supplied to the heaters of social housing, most of the times has a lower temperature than the weather, because the water comes through underground pipes, which are not in contact with the solar thermal radiation, or water storage tanks placed on the roofs of houses.

This section illustrates the variation of CO_2 emissions when the average temperature of the cold water is changed.

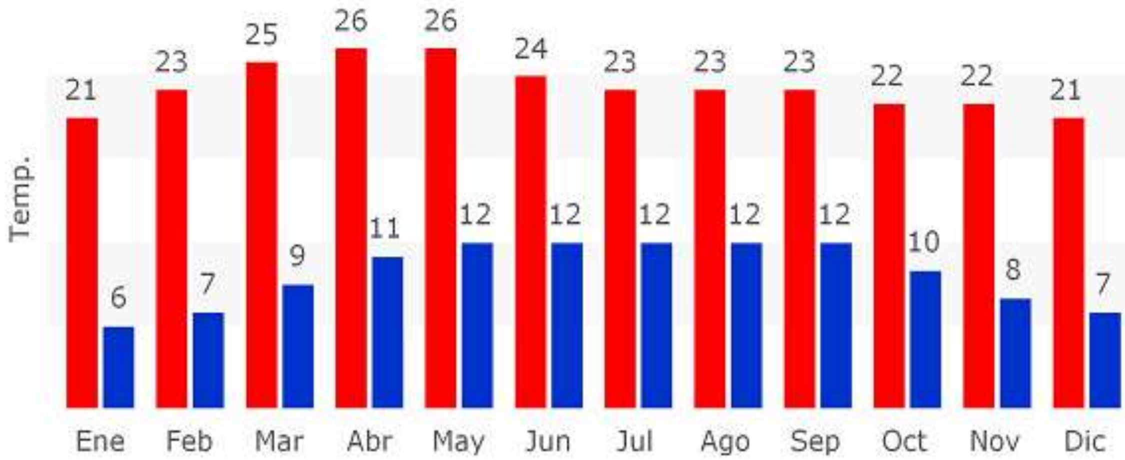
Emissions

The graph below shows the behavior of CO_2 emissions per person per year, in function of the variation of the site temperature; this graph was developed using the Voluntary Gold Standard methodology, developed by R&R in previous reports.



CO2 emissions per person according to site temperature.

The following graph shows the monthly average temperatures recorded in 2009 in Mexico City[7]. The blue columns represent the minimum for each month and the red ones are the highest reported. All figures are reported in Celsius.



Monthly average temperatures recorded in 2009 in Mexico City. Source: http://www.weather.com

[7] http://www.weather.com

COLD WATER STORED INTO HOT WATER PIPE

When we are ready to use hot water, at faucet and showers, we realize that hot water comes after a certain time. This "cold water" already passed through the heater before, but it was stocked into the pipeline before it was used and lost its energy.

The volume of water into the pipe between the heater and the devices, had consumed a certain amount of energy from the fuel in the heater, which means there was a corresponding amount of CO2 emissions due to this combustion.

This fact increases the carbon dioxide emissions, since the heaters, whether instantaneous or storage, are kept idling longer.

- In the instantaneous heaters, the water flow sensors activates the operation of heaters as there have a demand of hot water. This implies that since opening the hot water tap, the heater starts to work, but hot water does not come the user immediately.

- In Storage Heaters is something similar, except that the heater will not turn so immediately and do it when the water temperature in it is low

In both types of heaters when they stop using hot water at taps and showers, remains a volume of hot water in the pipes, which reaches to the room environment temperature, leading to a loss of energy.

In this section we present a study of CO_2 emissions that are not counting in Faulkner Project and might well be more carbon credits.

Analysis

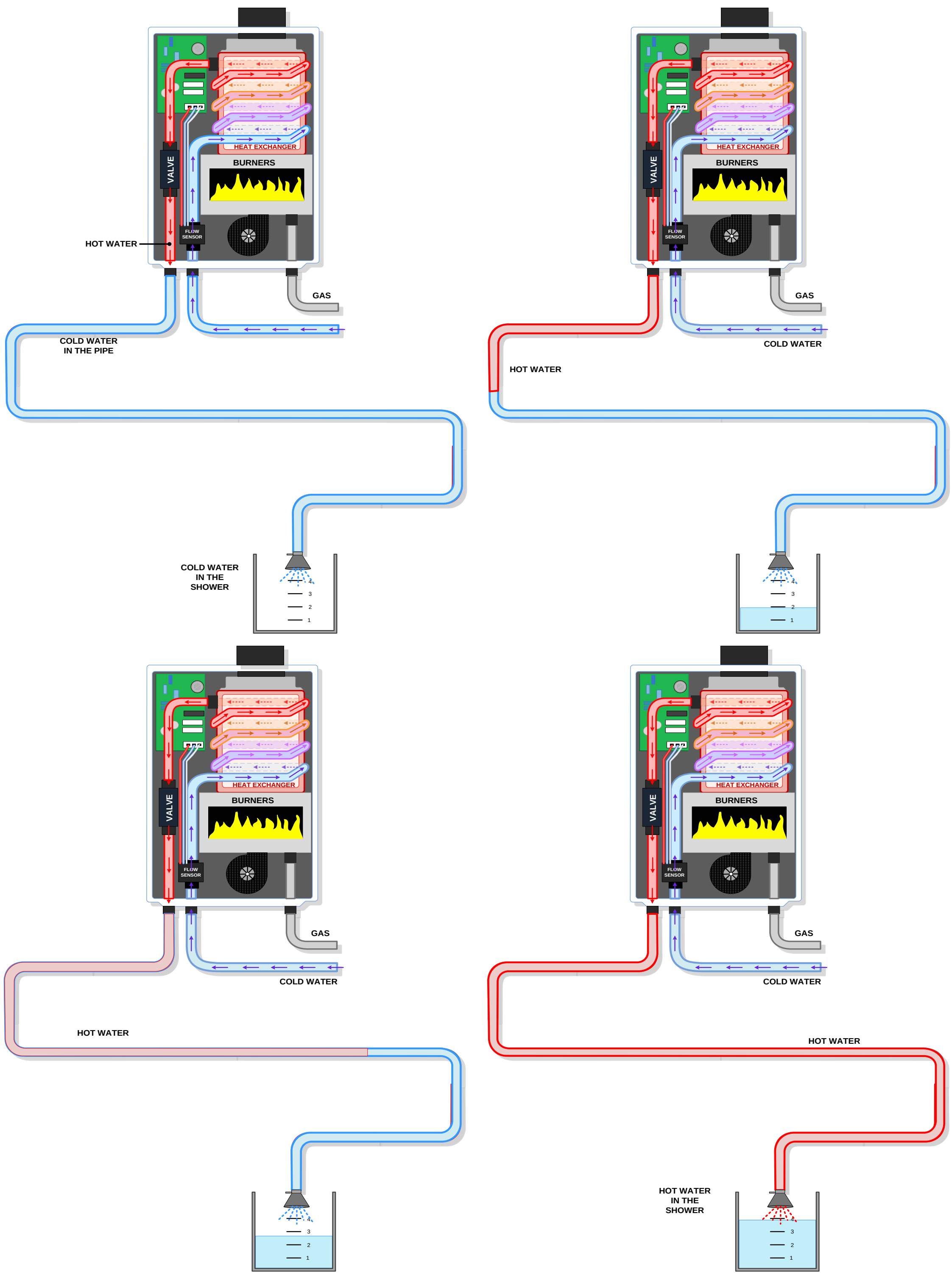
The following analysis is for an instantaneous heater and shows how does is the behavior of CO_2 emissions when taking into account the time the heater was kept turn on until the hot water reaches the point of consumption.

Displacing water stored into the pipe for hot water, take some time, this depending mainly on the distance between the heater and device. That time is the same time that the heater is operating without hot water uses. For Project Faulkner, that time is not considered in the calculation of CO_2 emissions mitigated

To determine the emissions for this fact, it is necessary to establish an average distance from the heater to the devices, and so calculate the time it takes to move the cold water to hot water use.

The following graph illustrates the movement of cold water stored into the pipe from the hot water heater. During the tour of hot water through the pipe, it also loses energy by convection. This process will be discussed in this document below.

Displacement of water stored into the hot water pipe.



Emissions

To sensitize with this factor, the next example is shown.

If we have a distance from the heater to the shower of 15 meters, with a ½ inch pipe diameter, the volume stored is:

$$V = transverse\ area_{pipe} * distance$$

$$V = \frac{\pi}{4} * \left\{(0.5\ [in]) * \left(\frac{0.0254[m]}{1[in]}\right)\right\}^2 * 15\ [m] * 1000\ \frac{litros}{m^3}$$

$$V = 1.9\ liters$$

This stored volume represents the amount of water that is heated, and whose energy is wasted by being left in the pipe. The total energy that was liberated by the fuel and was not used can be measured by calculating the energy required to raise the temperature of cold water until comfort temperature, divided by the heater efficiency:

$$Q = \frac{mCp\ \Delta T}{heater\ efficiency}$$

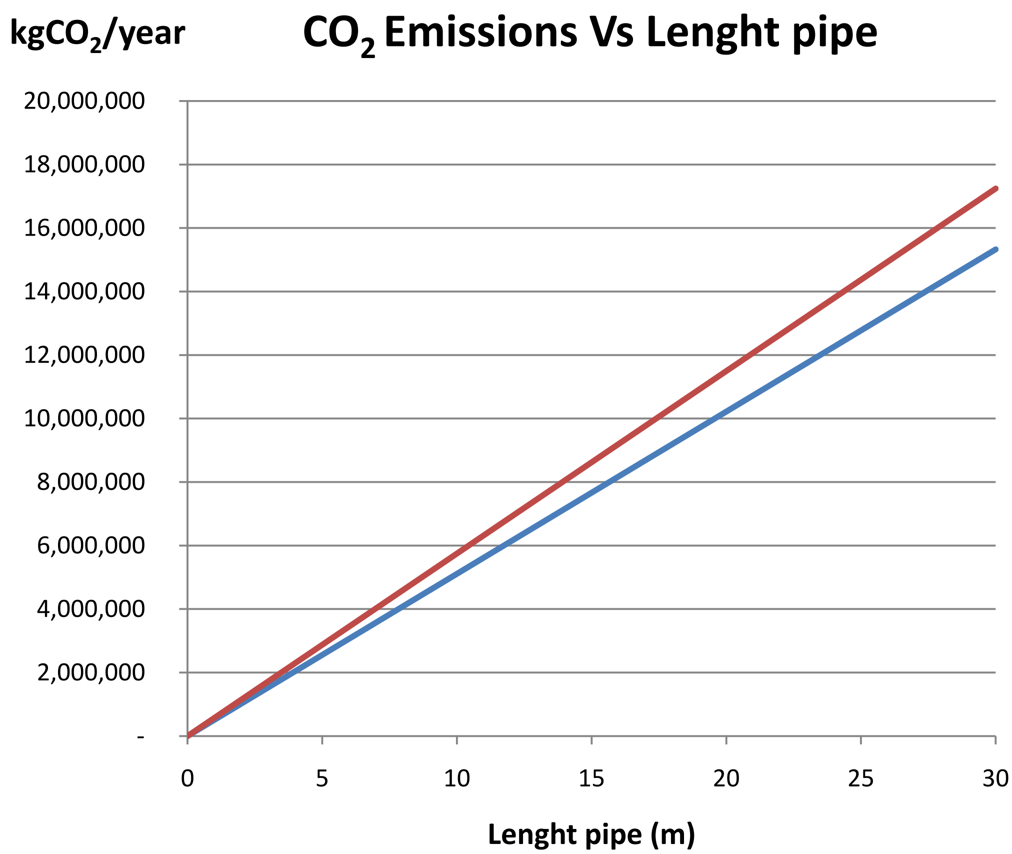
$$Q = \frac{1.9\ liters * 1 \left[\frac{kg}{liter}\right] * 4.186 \left[\frac{kJ}{kg°K}\right] * (55 - 15)[°C]}{85\%}$$

$$Q = 374\ kJ$$

Using the emission factor from IPCC[8] for Natural Gas (56.1 tCO_2/TJ) we obtained 0.2 $kgCO_2$, if this value is multiplied by the days of the year whern the heater is used, 7.66 $kgCO_2$/year is obtained. This emission value corresponds only to one person that takes shower once a day. In the case of using LPG (63.1 tCO_2/TJ) emissions of CO_2 per year would be of 8.62 $kgCO_2$/year per person is obtained. If we took the population of the Faulkner Project in Mexico City, one of the two values could be multiplied until 2 million times.

[8] Intergovernmental Panel on Climate Change, estos factores son utilizados actualmente por el Instituto Nacional de Ecología de México

The following graph presents the behavior of CO_2 emissions by varying the distance between the heater and the devices, considering a million showers.



CO2 emissions as a function of length pipe. Data per one million people.

CO_2 emissions increase in proportion to the distance between the heater and device, so in those houses where exist a great distance, there will be a considerable amount of emissions produced by this factor.

PIPE LOSSES

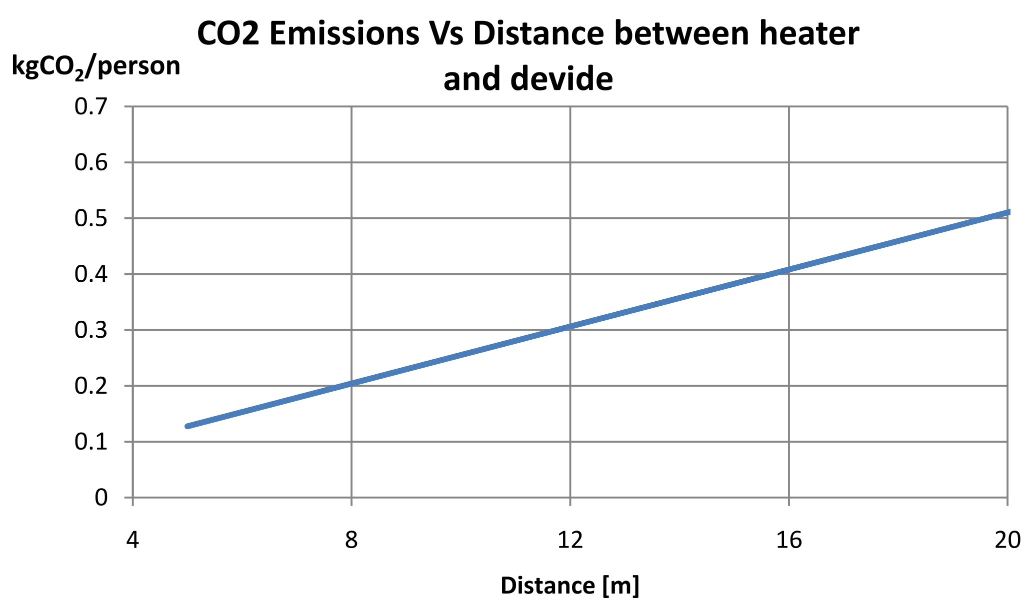
In the previous case the energy losses were shown by displacement of the existing cold water in the hot water pipes. However, loss caused by the displacement of this water it must add the losses for energy transmitted by the pipe convection.

Before moving cold water, the pipe has a temperature below the temperature of the hot water from instantaneous heaters. This can be considered for the case study as the ambient temperature or the temperature of 15 ° C that proposed in the project

Performing the calculation for heat transfer to pipe, the amount of heat transferred to the pipe is 1.458 W, if this quantity of energy is lost at the same time to moving cold water; the amount of energy transferred to the pipe is 16.6 kJ.

Though it is a small amount of energy lost in the pipeline, it is noteworthy that if this value is multiplied to the number of days per year, 0.38 kgCO_2 per person is obtained. When the value is multiplied to the Faulkner Project's population in Mexico City, the amount of CO_2 would be quite significant.

The graph below shows the variation in CO_2 emissions per person per year and distance between the heater and the device.



ANNEX 1

LP GAS COMBUSTIÓN

MAYOR RANGE

	OXÍGEN AND AIR KG/KG FUEL				PRODUCTS KG/KG FUEL					
	% WEIGHT	O2	N2	AIR	CO2	SO2	H2O	N2	O2	GASES
CARBON	82.26	2.192	7.282	9.474	3.015			7.282		10.296
HIDROGEN	17.74	1.408	4.676	6.084			1.585	4.676		6.262
SULFUR	0.00	0.000	0.000	0.000		0.000		0.000		0.000
OXÍGEN	0.00	0.000	0.000	0.000				0.000		0.000
CO2	0.00				0.000					0.000
NITROGEN	0.00							0.000		0.000
FREE WATER	0.00						0.000			0.000
TOTAL	100	3.603	11.967	15.569	**3.015**	0.000	1.585	11.958	0.000	16.558

SITE CONDITIONS

ASNM	2234	Meters		
PB= 1013.25-asnm*0.119659+asnm^2*0.00000519 [mbar]				
PB =	771.83	mbar	0.762	kg/cm2
Dry bulb temperature			23	°C
Air Humidity %			78	%
O2 percentage in gases (dry base)			5.2	%

AIR EXCESS
For LP GAS
EXCESS % = 2.42 + (%O2)*2.71 + 0.482*((%O2)^2)

MASS BALANCE	OXÍGEN AND AIR KG/KG FUEL				PRODUCTS KG/KG FUEL					
	% WEIGHT	**O2**	**N2**	**AIR**	**CO2**	**SO2**	**H2O**	**N2**	**O2**	**GASES**
AIR EXCESS %	29.545	1.064	3.533	4.597				3.533	1.064	4.597
Excess air		4.664	15.491	20.155						
Air Humidity	0.0119	kg H2O/kg dry air		0.240			0.240			0.240
TOTAL				20.394	**3.015**	0.000	1.826	15.491	1.064	21.396

LP GAS DENSITY	560	Kg/m3

EMISIÓN FACTOR	**1688.40**	Kg CO2/m3LPG

LP GAS COMBUSTIÓN

MINOR RANGE

	% WEIGHT	OXÍGEN AND AIR KG/KG FUEL O2	N2	AIR	PRODUCTS KG/KG FUEL CO2	SO2	H2O	N2	O2	GASES
CARBON	81.79	2.180	7.240	9.420	2.998			7.240		10.238
HIDROGEN	18.21	1.445	4.800	6.245			1.627	4.800		6.427
SULFUR	0.00	0.000	0.000	0.000		0.000		0.000		0.000
OXÍGEN	0.00	0.000	0.000	0.000				0.000		0.000
CO2	0.00				0.000					0.000
NITROGEN	0.00							0.000		0.000
FREE WATER	0.00						0.000			0.000
TOTAL	100	3.625	12.040	15.665	**2.998**	0.000	1.627	12.040	0.000	16.665

SITE CONDITIONS

ASNM	2234	Meters		
PB= 1013.25-asnm*0.119659+asnm^2*0.00000519 [mbar]				
PB =	771.83	mbar	0.762	kg/cm2
Dry bulb temperature			23	°C
Air Humidity %			78	%
O2 percentage in gases (dry base)			5.2	%

AIR EXCESS

For LP GAS

EXCESS % = 2.42 + (%O2)*2.71 + 0.482*((%O2)^2)

MASS BALANCE	**% WEIGHT**	OXÍGEN AND AIR KG/KG FUEL **O2**	**N2**	**AIR**	PRODUCTS KG/KG FUEL **CO2**	**SO2**	**H2O**	**N2**	**O2**	**GASES**
AIR EXCESS %	29.545	1.071	3.557	4.628				3.557	1.071	4.628
Excess air		4.696	15.598	20.293						
Air Humidity	0.0119	kg H2O/kg dry air		0.241			0.241			0.241
TOTAL		20.535		20.394	**2.998**	0.000	1.869	15.598	1.071	21.535

LP GAS DENSITY 560 Kg/m3

EMISIÓN FACTOR **1678.88** Kg CO2/m3 LPG

ANEXO 2

NATURAL GAS COMBUSTIÓN

MAYOR RANGE

		OXIGEN AND AIR KG/KG FUEL			PRODUCTS KG/KG FUEL					
	% WEIGHT	O2	N2	AIR	CO2	SO2	H2O	N2	O2	GASES
CARBON	75.94	2.024	6.722	8.746	2.783			6.722		9.505
HIDROGEN	24.06	1.909	6.342	8.252			2.150	6.342		8.492
SULFUR	0.00	0.000	0.000	0.000		0.000		0.000		0.000
OXÍGEN	0.00	0.000	0.000	0.000				0.000		0.000
CO2	0.00				0.000					0.000
NITROGEN	0.00							0.000		0.000
FREE WATER	0.00						0.000			0.000
TOTAL	100	3.933	13.064	16.998	**2.783**	0.000	2.150	13.064	0.000	17.998

SITE CONDITIONS

ASNM	2234	metros		
PB= 1013.25-asnm*0.119659+asnm^2*0.00000519 [mbar]				
PB =	771.83	mbar	0.762	kg/cm2
Dry bulb Temperature			23	°C
Air Humidity %			78	%
O2 percentage in gases (dry base)			5.2	%

AIR EXCESS

For NATURAL GAS

EXCESS % = 2.42 + (%O2)*2.71 + 0.482*((%O2)^2)

MASS BALANCE		OXÍGEN AND AIR KG/KG FUEL			PRODUCTS KG/KG FUEL					
	% WEIGHT	**O2**	**N2**	**AIR**	**CO2**	**SO2**	**H2O**	**N2**	**O2**	**GASES**
AIR EXCESS %	29.545	1.162	3.860	5.022				3.860	1.162	5.022
Excess air		5.095	16.924	22.020						
Air Humidity	0.0119	kg H2O/kg dry air		0.262				0.262		
TOTAL				22.282	**2.783**	0.000	2.412	16.924	1.162	23.282

NATURAL GAS DENSITY 0.6 Kg/m3

EMISSION FACTOR **1.6698** Kg CO2/m3 NLG

NATURAL GAS COMBUSTION
MINOR RANGE

	OXIGEN AND AIR	KG/KG FUEL			PRODUCTS		KG/KG FUEL			
	% WEIGHT	O2	N2	AIR	CO2	SO2	H2O	N2	O2	GASES
CARBON	71.10	1.895	6.294	8.189	2.606			6.294		8.900
HIDROGEN	23.70	1.881	6.247	8.128			2.118	6.247		8.365
SULFUR	0.00	0.000	0.000	0.000		0.000		0.000		0.000
OXIGENO	0.20	-0.002	-0.007	-0.009				-0.007		-0.007
CO2	0.00				0.000					0.030
NITROGEN	5.00							0.050		0.020
FREE WATER	0.00						0.000			0.000
TOTAL	100	3.774	12.534	16.308	**2.606**	0.000	2.118	12.584	0.000	17.308

SITE CONDITIONS

ASNM 2234 meters

PB= 1013.25-asnm*0.119659+asnm^2*0.00000519 [mbar]

PB =	771.83	mbar	0.762	kg/cm2
Dry bulb Temperature			23	°C
Air Humidity %			78	%
O2 percentage in gases (dry base)			5.2	%

AIR EXCESS

For NATURAL GAS

EXCESS % = 2.42 + (%O2)*2.71 + 0.482*((%O2)^2)

MASS BALANCE	OXIGEN AND Y AIR	KG/KG FUEL			PRODUCTS		KG/KG FUEL			
	% WEIGHT	**O2**	**N2**	**AIR**	**CO2**	**SO2**	**H2O**	**N2**	**O2**	**GASES**
AIR EXCESS %	29.545	1.115	3.703	4.818				3.703	1.115	4.818
Excess Air		4.889	16.238	21.126						
Air Humidity	0.0119	kg H2O/kg dry air		0.251			0.251			0.251
TOTAL				21.378	**2.606**	0.000	2.369	16.268	1.115	22.378

NATURAL GAS DENSITY 0.6 Kg/m3

EMISIÓN FACTOR **1.5636** Kg CO2/m3 NLG

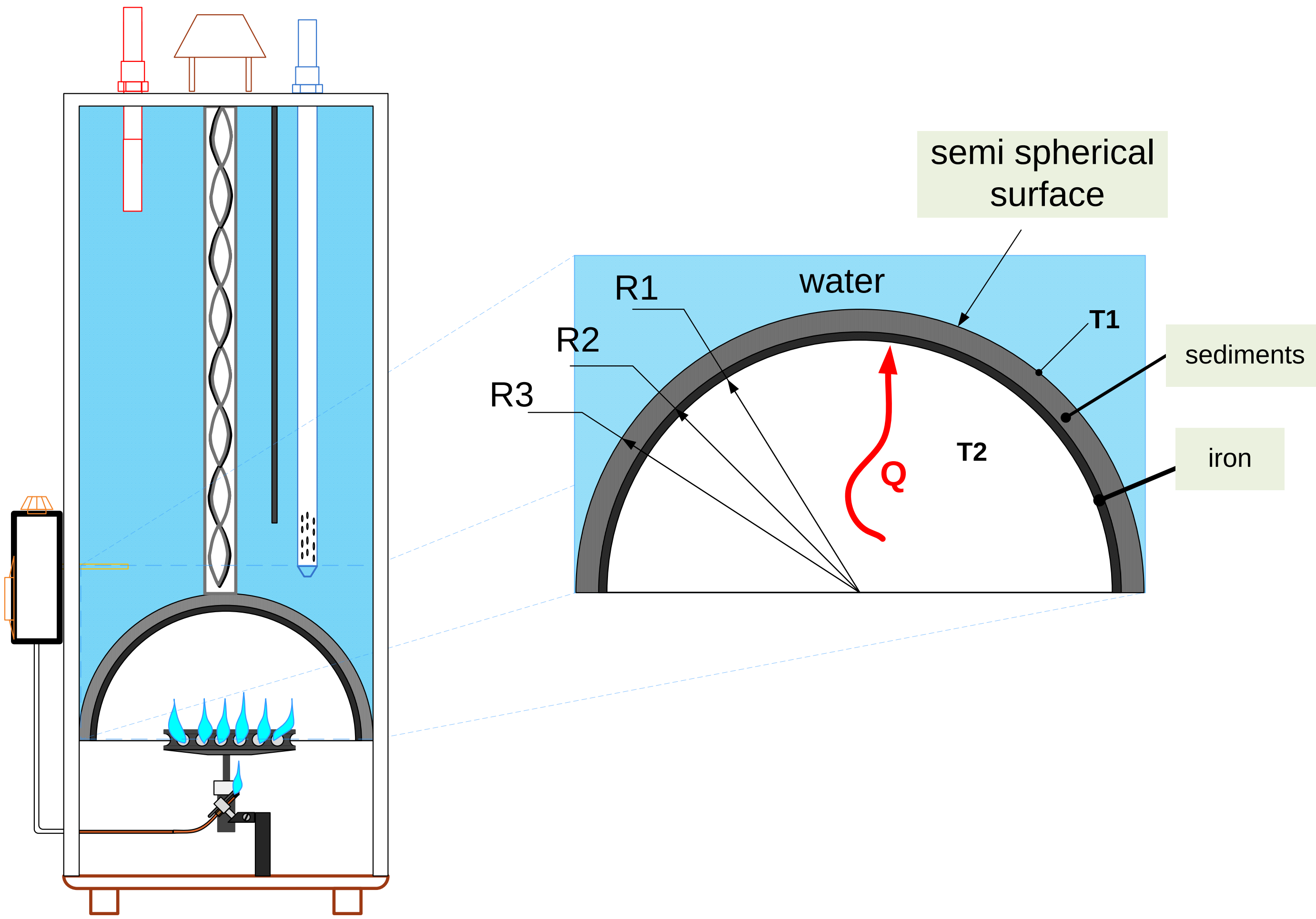
ANNEX 3

T [C]	P [KPa]	FT	FP	Efficiency
14.0	1.737	1.107	0.77677	70%
14.1	1.737	1.099	0.77678	71%
14.2	1.738	1.092	0.77679	71%
14.3	1.739	1.084	0.77679	72%
14.4	1.739	1.076	0.77680	72%
14.5	1.740	1.069	0.77680	73%
14.6	1.740	1.062	0.77681	73%
14.7	1.741	1.054	0.77682	74%
14.8	1.742	1.047	0.77682	74%
14.9	1.742	1.040	0.77683	75%
15.0	1.743	1.033	0.77683	75%
15.1	1.743	1.026	0.77684	76%
15.2	1.744	1.020	0.77685	76%
15.3	1.745	1.013	0.77685	77%
15.4	1.745	1.006	0.77686	77%
15.5	1.746	1.000	0.77686	78%
15.6	1.746	0.994	0.77687	78%
15.7	1.747	0.987	0.77688	79%
15.9	1.748	0.975	0.77689	80%

*We used the ideal gas equation to obtain the data table results.

ANNEX 4

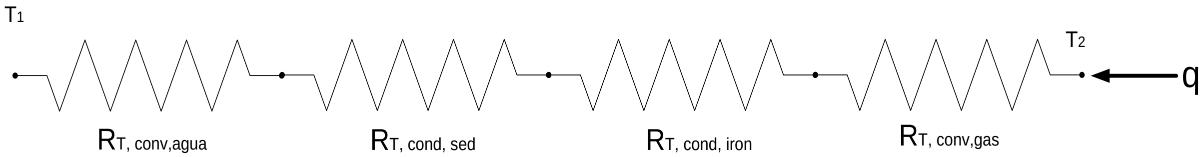
Considering the interface as a hollow semi-spheric, the analyzed system is the next:



Considerations:

- Only consider the conduction heat transfer
- A semi-spherical analysis surface
- The R3 radius is variable, for this exercise will be considered from 0.5 mm to 1 cm
- Hot gas temperature 400 ° C
- Conduction is radial in unidirectional way

The system could be considered like:



The heat transfer equation that was used is:

$$q = 0.5 * \frac{(T2 - T1)}{\frac{1}{4\pi h_g (R1)^2} + \frac{1}{4\pi k_{iron}}\left[\frac{1}{R1} - \frac{1}{R2}\right] + \frac{1}{4\pi k_{sed}}\left[\frac{1}{R2} - \frac{1}{R3}\right] + \frac{1}{4\pi h_a (R3)^2}}$$

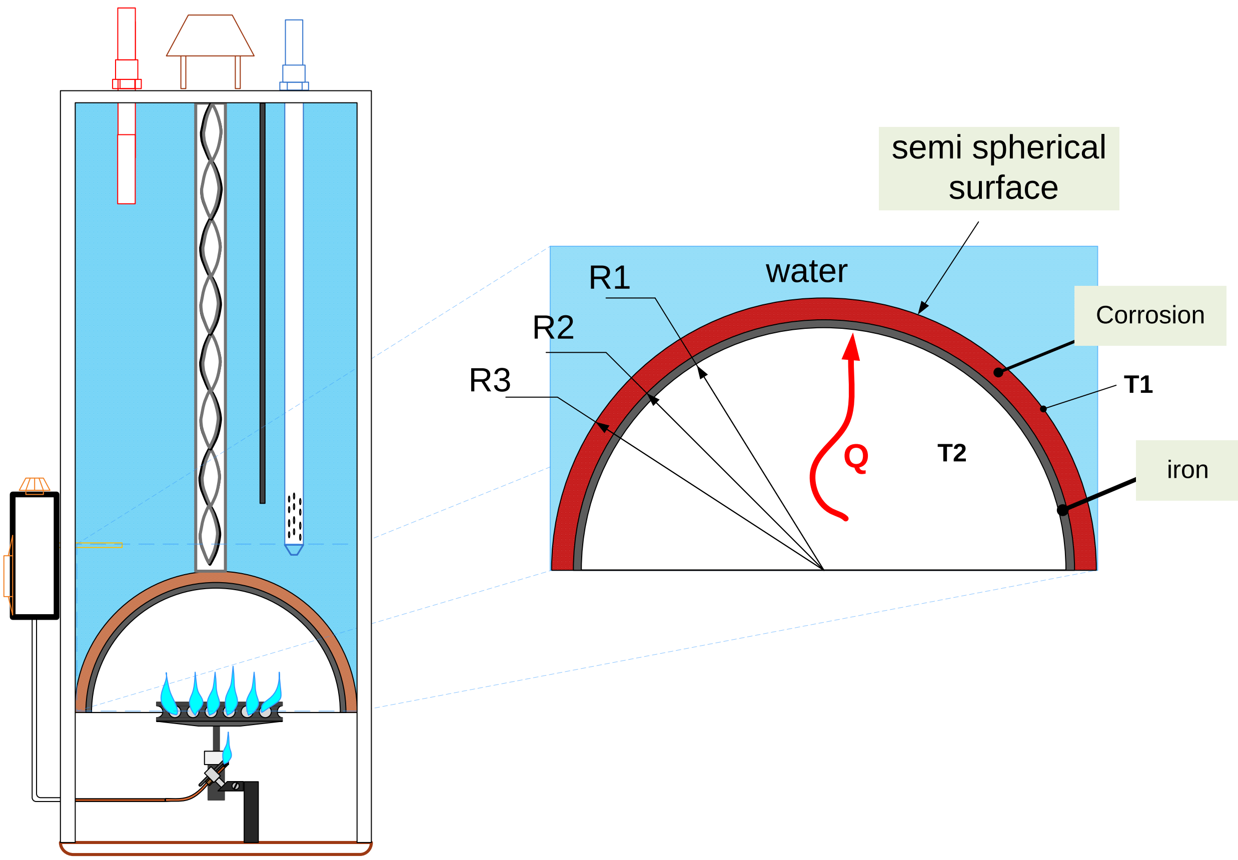
Where:

- k_{iron} , is the thermal conductivity of iron.
- k_{sed} , is the thermal conductivity of sediments.

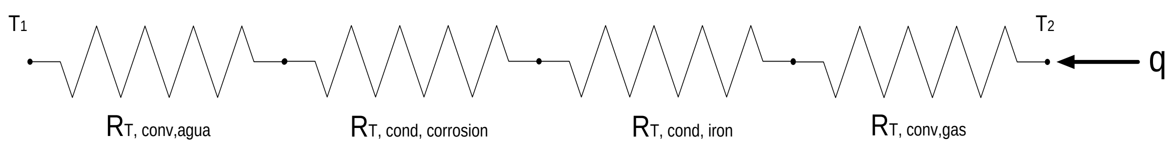
ANNEX 5

Considering the diagram and taking into account the following conditions:

- Stable state conditions
- A semi-spherical analysis surface
- Unidirectional heat transfer in radial way
- Constant properties



The system could be considered like:



Where:

- T_1, is the water temperature within the water heater at initial conditions.
  T_2, is the temperature of the external surface, generated by combustion.
- $R_{Tcond,\ corrosion}$, is the conduction thermal resistance of heat transfer because of corrosion thickness.
- $R_{T,cond,\ iron}$, is the conduction thermal resistance of heat transfer because of the material of the water heater (iron).
- q, is the heat transfer per unit of time.

The expression that allows calculate heat transfer under these considerations, is the following:

$$q = 0.5 * \frac{(T2 - T1)}{\frac{1}{4\pi \boldsymbol{h}_g (R1)^2} + \frac{1}{4\pi k_{iron}}\left[\frac{1}{R1} - \frac{1}{R2}\right] + \frac{1}{4\pi k_{corr}}\left[\frac{1}{R2} - \frac{1}{R3}\right] + \frac{1}{4\pi \boldsymbol{h}_a (R3)^2}}$$

Where:

- k_{iron} is the thermal conductivity of iron.
- k_{corr} is the thermal conductivity of corrosion.

ANNEX 6

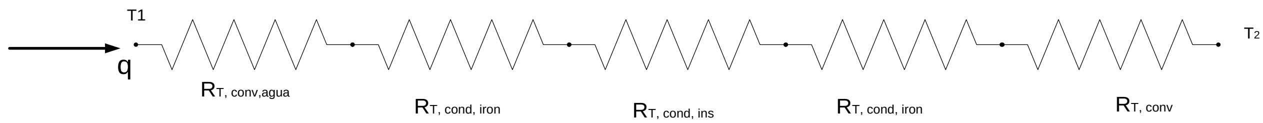
COMBUSTION GAS PIPE		
Inner radius	0.0400	m
Thermal conductivity	50.0	[m^2]
Length	0.7	[m]
COMBUSTION GAS		
Conductivity	0.422	[W/m*K]
Viscosity	0.0018	[centipoises]
Thermal Capacity	0.0974	[kJ/kg*K]
Convective coefficient	109.9	[W/m^2*K]
Convective resistance	0.0098	[m^2*KW]
Average temperature	350	[ºC]
IRON OXIDES		
Thermal conductivity	10.0000	[W/m*K]
HEAT TRANSFER		
Global coefficient	97.5	[W/m^2*K]

ANNEX 7

The model used for calculating heat transfer has the following considerations:

- Stable state conditions
- There are only heat transfer by conduction
- The heat transfer surface is a cylinder
- The conduction is unidirectional in radial way

The analyzed system can be simplified as shown below:

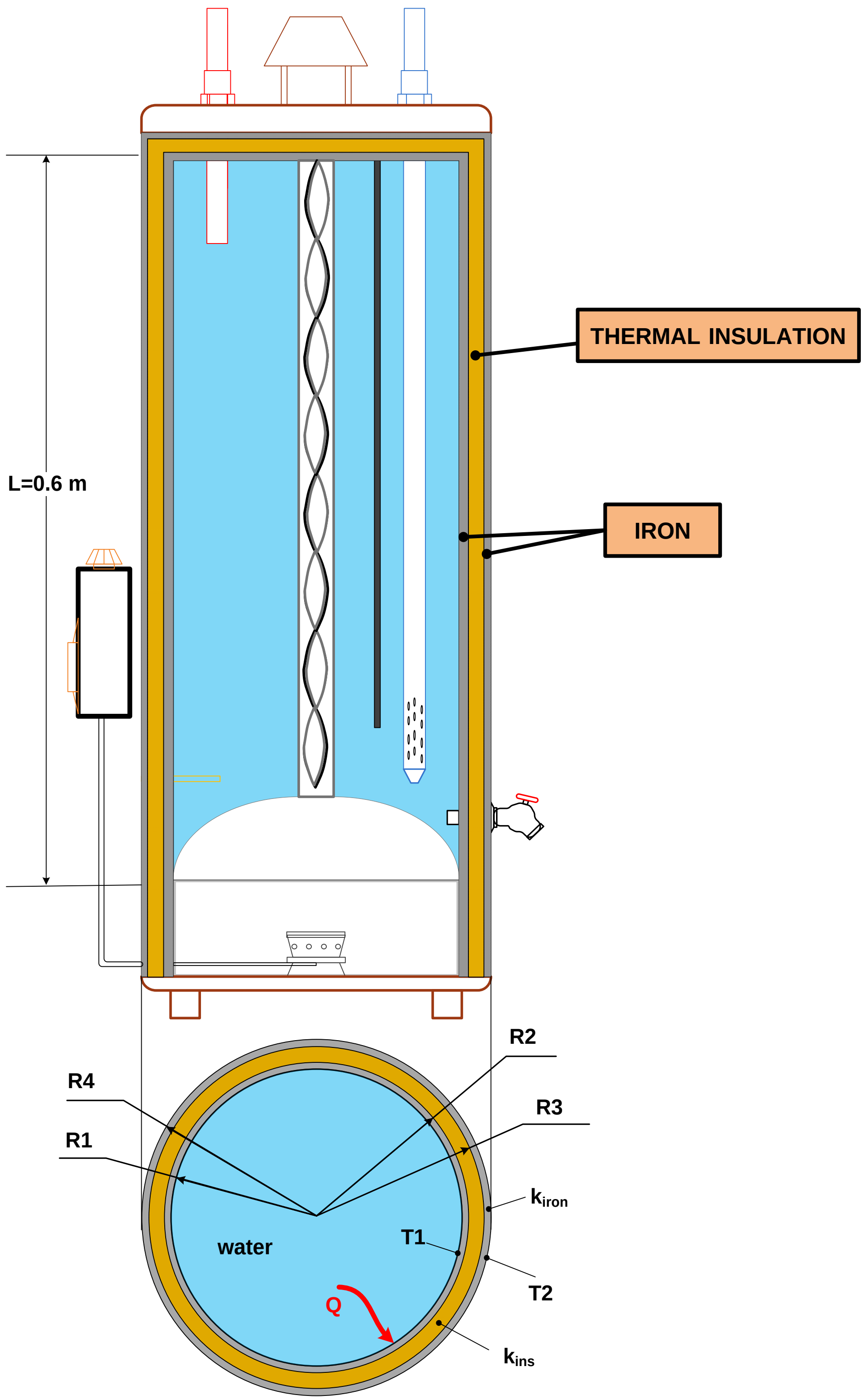


And the mathematic expression that was considered is:

$$q = \frac{(T1 - T2)}{\frac{1}{2\pi L h_a R1} + \frac{\ln\left(R2/R1\right)}{2\pi L k_{iron}} + \frac{\ln\left(R3/R2\right)}{2\pi L k_{ins}} + \frac{\ln\left(R3/R4\right)}{2\pi L k_{iron}} + \frac{1}{2\pi L h_{aire} R4}}$$

Where:

- T_2, is the external surface temperature in water heater; the same like the climate, 20°C
- T_1, is the internal surface temperature in water heater; the same like water within water heater, 50°C
- R_1, inner radius of first iron layer
- R_2, outer radius of first iron layer
- R_3, measured radius from the center of the boiler to outside of insulating layer
- R_4, measured radius from the center of the boiler to outside the last layer of metal.
- L, boiler length where the heat transfer take places
- k_{iron} , termal conductivity of iron
- k_{ins} , thermal conductivity of insulance


THERMAL INSULATION
IRON
L=0.6 m
R2
R4
R3
R1
k_{iron}
water
T1
T2
Q
k_{ins}