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Study, dimensioning and realization of a fire fighting

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Abstract

An analysis of the SCB-Lafarge Onigbolo fire network shows that in addition to its advanced age, it presents a number of irregularities. Indeed, this network delivers a low pressure to the water points. For example, the water cannon receives a pressure of 2.5 bars when it requires a pressure of 3.5 bars. This network also has an insufficient number of water points around the fuel piles. For example, there is only one fire hydrant around the petcoke hall containing 30,000 tons of fuel. Moreover, in case of a power cut, this network does not work because it is supplied by electric pumps. After the study of the various problems, it was decided to build a new fire network. This network is dedicated only to fire fighting and is supplied by a diesel pump. It is made of high-density polyethylene and stainless-steel pipes. These pipes are of nominal diameter constituting the secondary and main sections respectively. The number of fire hydrants has been doubled around the fuel piles and the water tank has been sized accordingly. This new network is capable of supplying two fire hydrants simultaneously with the right pressure and flow rate, in addition to a reinforced fire hydrant. The cost of the network is eighty million two hundred and seventy-seven thousand four hundred and sixty-four point five (80 277 464.5) CFA francs.

Keywords: Fire-fighting system; Low pressure; Diesel pump; Fire hydrant

1. Introduction

Industrial risk is defined as an accidental event occurring on an industrial site and leading to serious consequences for personnel, local residents, property and the environment [1]. This event is linked to the nature of the products present on the industrial site, to the manufacturing processes, to the installations, to human factors and to external phenomenon [2]. The industrial risk is manifested by three effects: the thermal effect, the mechanical effect and the toxic effect [3]. The thermal effect is linked to the combustion of a flammable or combustible product or to an explosion. For combustion to occur, three elements must be present: the fuel, the oxidizer and the activation energy [4]. When combustion is not controlled, it spreads in time and space, giving rise to a fire [5]. Fires can cause great losses to the industry and serious damage to the people working there [6]. To fight a fire, industries are equipped with a fire-fighting network. This network is a set of means and processes implemented to fight a fire effectively [7]. Firefighting is carried out by reducing or even eliminating at least one of the elements necessary for combustion [8]. It allows the fire to be brought under control quickly so that it does not develop into a major event that is difficult to control [6]. The labor code in its article L. 4121-1 of October 1, 2017, stipulates that the employer takes the necessary measures to ensure the safety and protect the physical and mental health of workers [9]. It is in this perspective and concerned about the safety of its employees and property that SCB-Lafarge has been equipped since the 1980s with a fire-fighting water network that unfortunately

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now has irregularities. It is with the aim of remedying these anomalies that the present work entitled: STUDY, DIMENSIONING AND REALIZATION OF A FIRE-FIGHTING NETWORK. In the study, we have referred to the NFPA standards. The NFPA (National Fire Protection Association) founded in the United States, establishes and updates fire protection and prevention measures [10].

2. Material and methods

The main components of the fire network are the pipes and accessories, the water points and the diesel engine.

The fire network, of branched type, is made up of a main pipe and a secondary one.

This network is located close to the lorry traffic roads or sometimes even crosses them. It is then underground in order to be protected from truck traffic, falling tools, equipment, limestone blocks and bad handling. Since the pump that feeds the network is above ground, a portion of the network will be above ground. The network will then be made up of an exposed part and an underground part. To ensure that the exposed portion of the network will withstand the various impacts and falls and the corrosive effect of the water, it will be made of stainless steel. The underground portion will be made of high-density polyethylene (HDPE).

The pipe accessories available on the network are elbows and tee fittings. These are used to change direction and connect the secondary pipe to the main pipe, respectively.

Water supply points are fire-fighting equipment designed to provide the water pressure and flow required for fire-fighting. On the network, the water points present are the fire hydrants, the armed fire valve (AFV) and the water cannon.

Table 1 shows the minimum hydraulic requirements for each water point.

Table 1 Hydraulic characteristics of water points

Water points	Flow rate (m^3/h)	Pressure (bars)	Number
Fire hydrant [11]	60	1	5
Water cannon [12]	90	3.5	1
AFV [13]	9	2.5	1

The motor pump supplies water to the various water points through the pipes. It draws water from the water supply and pumps it into the pipes at a higher pressure.

2.1. Modeling of Pipelines and Pipe Fittings

Each group of pipes (main and secondary) is characterized by the same pipe diameter.

2.1.1. Secondary pipe diameter

The water flow velocity in the firefighting pipelines must not exceed 3.5 m/s [14]. In order to have a fast response of the network to a fire, the minimum velocity in the pipes is chosen equal to à 1 m/s. We can therefore write:

$$1\ m/s \leq V \leq 3.5\ m/s \quad (1)$$

The flow velocity of a fluid in a pipe of circular section is given by the relation:

$$V = \frac{4 \times Q}{\pi \times D^2}\ [14] \quad (2)$$

V: flow velocity (m/s);
: flow rate in the pipe (m^3/h) ;
D: diameter of the pipe (m).
From equation (5), we can write:

$$D = \sqrt{\frac{4 \times Q}{\pi \times V}} \ (3)$$

$$1 \leq V \leq 3.5 \Longrightarrow \pi \times 1 \leq \pi \times V \leq \pi \times 3.5 \ (4)$$

$$\Longrightarrow \frac{1}{\pi \times 3,5} \leq \frac{1}{\pi \times V} \leq \frac{1}{\pi \times 1} \ (5)$$

$$\Longrightarrow \frac{4 \times Q}{\pi \times 3.5} \leq \frac{4 \times Q}{\pi \times V} \leq \frac{4 \times Q}{\pi \times 1} \ (6)$$

$$\Longrightarrow \sqrt{\frac{4 \times Q}{\pi \times 3.5}} \leq \sqrt{\frac{4 \times Q}{\pi \times V}} \leq \sqrt{\frac{4 \times Q}{\pi \times 1}} \ (7)$$

Soit $D_{min} \leq D \leq D_{max}$ avec

$$D_{min} = \sqrt{\frac{4 \times Q}{\pi \times 3.5}} \ ; D = \sqrt{\frac{4 \times Q}{\pi \times V}} \ et \ D_{max} = \sqrt{\frac{4 \times Q}{\pi \times 1}} \ (8)$$

Relation 4.4 provides the range of pipe diameters capable of conveying the flow rate (Q) of fluid to each water point. It therefore allows the selection of the diameter of the secondary pipe. The minimum pipe diameter to be used to connect a fire hydrant or water cannon to the water system is Ø=100 mm [14].

2.1.2. Diameter of the main pipe

It is crucial to select the main piping in such a way that it is capable of supplying a reasonable number of water points simultaneously. This capacity of the pipe is related to the maximum flow rate through it.

For each pipe diameter, the maximum flow rate that can pass through it is:

$$Qmax = S \times Vmax \ (9)$$

With S: the cross-sectional area of the pipe and V_max the velocity of the water ($Vmax = 3.5m/s$)

$$S = \frac{\pi \times D^2}{4} \ (10)$$

2.1.3. Linear Pressure Losses

The linear pressure losses are proportional to the length of the pipe, to the square of the fluid velocity and inversely proportional to the pipe diameter. They are given by the relationship:

$$J_L = -\lambda \frac{V^2 \times L}{2 \times d} \ [15] \ (11)$$

Where V: is the fluid flow velocity (m/s);

d :is the inside diameter of the pipe (m);
L: the length of the pipe (m);
λ : the linear pressure drop coefficient. It varies according to the Reynold's number.

The Reynolds number (Re) is obtained by the formula:

$$Re = \frac{V \times d}{\nu} \ [15] \ (12)$$

Where: V is the fluid flow velocity (m/s); d is the inside diameter of the pipe (m) and ν is the kinematic viscosity of the fluid in m^2/s.

For laminar flow, $e < 2000$;

$$\lambda = \frac{64}{Re} \; (\,Poisseuille\ formula) \; [15] \; (13)$$

For smooth turbulent flow, $2000 < Re < 10000$:

$$\lambda = 0.316 \times Re^{-0,25} \; [15] \; (14)$$

For rough turbulent flow, 10000<Re :

$$\lambda = 0.79\sqrt{\frac{\epsilon}{d}} \; [15] \; (15)$$

ϵ: the roughness of the internal surface of the pipe (mm)

2.1.4. Singular Pressure Losses

The singular pressure losses are measurable at the changes of direction and section of the pipes of the installation. In the network, they are caused by elbows and tee fittings and are determined by the expression:

$$J_s = -K_s\frac{V^2}{2} \; [15] \; (16)$$

Where s: the index of the shape of the pipe;

K_s: the pressure loss coefficient. It depends on the nature and the geometry of the accident of form. Its value is established by the manufacturers in their catalogs. In 45° and 90° round bends with a ratio r/d equal to 2, the coefficient K_s is respectively as follows:

$$k_{45°} = 0.073 \; et \; k_{90°} = 0.145 \; [16]$$

r : radius of curvature of the bend in meters, d: internal diameter of the pipe in meters

The pressure drop coefficients in the tee fittings are given in Table 2.

Table 2 Coefficient of singular pressure losses in tee fittings [16]

$\frac{Q_b}{Q_t}$	**0**	**0,2**	**0,4**	**0,6**	**0,8**	**1**
k_r	0.04	-0.08	-0.05	0.07	0.21	0.35*
k_b	0.95*	0.88	0.89	0.95	1.10	1.28

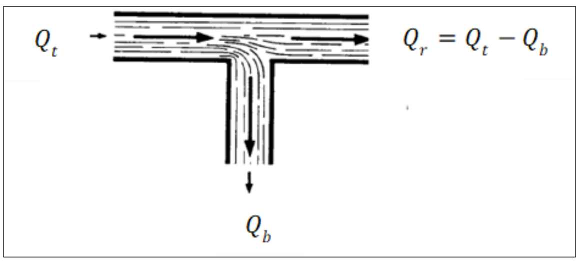

Figure 1 Flow in a tee connection [14]

k_r and k_b are the singular pressure drop coefficients in the cross and side branches respectively;

Q_b and Q_t are respectively the fluid flow in the side branch and the inflow;

2.1.5. Total pressure drops

The total pressure drops(J) in the circuit is the sum of the singular and linear pressure drops. We have then:

$$J = J_L + J_s \text{ [15] (17)}$$

2.2. Modeling of the water points

The modeling of the water points will consist in the determination of the pressure necessary to supply the water points. It will be done with Bernoulli's theorem. For a real incompressible fluid flowing through two sections$S1$ *and* $S2$, this theorem is stated as follows:

$$\frac{1}{2}\left({V_2}^2 - {V_1}^2\right) + \frac{1}{\rho}(P_2 - P_1) + g(z_2 - z_1) = J_{12} \text{ [4] (18)}$$

Where:

J_{12} : is the sum of all singular and linear pressure losses between sections (1) and (2);
V_1 *and* V_2 : the velocities of the fluid respectively at the points of sections (1) and (2);
P_1 *and* P_2 : the pressures respectively at the points of sections (1) and (2);
z_1 *and* z_2 : the heights of the sections respectively at points (1) and (2).

From the formula (14), the expression of the necessary pressure to supply the water points is:

$$P_1 = P_2 - \rho \times \left(J_{12} - \frac{1}{2}\left({V_2}^2 - {V_1}^2\right) - g(z_2 - z_1)\right) \text{ (19)}$$

P_1 : is the pressure supplied by the pump to supply the water point;
P_2 : is the water pressure measured at the water point port.

2.3. Modeling of the diesel motor pump

The modeling of the pump allows to study the behavior of this one during the supply of the network through the determination of its operating point.

Each pump, depending on the diameter of its impeller and its speed of rotation, is characterized by the height-flow curve $H = f(Q)$ which translates the variations of the different heights as a function of the flow rate [6].

The operating point of a pump is the point of intersection of its head-flow curve $H = f(Q)$ with the characteristic curve $Hc = f(Q)$ of the pipe. The characteristic curve Hc is determined with the following formula:

$$Hc = Hg + R \times Q^2 \text{ [17] (20)}$$

Hg : the geometric height of the pipe at the point considered.
$R \times Q^2$: the pressure drops at the point considered (m);
Q : the flow rate of the pipe(m^3/h) ;
R : the coefficient that characterizes the resistance of the pipe;

$$R = 1.1 \times \frac{8 \times \lambda \times L}{\pi^2 \times D^5 \times g} \text{ [17] (21)}$$

L and D respectively the length and diameter of the pipe
g: the acceleration of gravity (9.81 m/s^2) ;
λ : the Darcy friction coefficient ;

2.4. Modeling of the cavitation phenomenon

Cavitation is a phenomenon that occurs when the pressure of the liquid flowing in the pipes falls below its vapor pressure. The liquid vaporizes, forming small pockets of vapor or bubbles. The bubbles formed are transported to areas of higher pressure where they condense. They implode at high frequencies forming a shock wave which creates very strong local overpressures. The damage caused by this phenomenon is cavitation corrosion of the pump impellers, increased noise and vibration generated by the pump and a drop in pump performance (lower head, flow rate and efficiency).

To avoid this phenomenon, the minimum available suction load ($NPSH_d$) must be greater than the minimum required net suction load ($NPSH_R$) provided by the pump manufacturer [6]:

$$NPSH_d > NPSH_R \ (22)$$

For a pump working under vacuum, the minimum available suction load is given by the relationship:

$$NPSH_d = \frac{P_0}{g \times \rho} - H_a - (J_a + T_v) \ [16] \ (23)$$

With P_0: the pressure in meters of water column at the suction point in (m);

ρ: the density of the fluid;
g: the acceleration of gravity;
H_a: the suction height in (m)
J_a: pressure drop at suction in (m);
T_v: the maximum vapour pressure that the air can support at a given temperature.

Table 3 shows the vapour pressure of the pumped water as a function of temperature.

Table 3 Vapor pressures of water according to temperature [16]

T(°C)	**00**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
$T_v(m)$	0.06	0.125	0.238	0.432	0.752	1.25	2.03	3.17	4.82	7.14	10.33

2.5. Modeling of the water reserve

The water tank must have a capacity to supply the fire system for at least two hours.

$$V = 2 \times D \ (24)$$

With: V *and* D respectively the volume of the water tank and the maximum cumulative flow in the network.

3. Results

3.1. Results of the modelling of the pipes and pipe accessories

3.1.1. Secondary pipeline

Table 4 Permissible diameter range

Section	**Hydrant considered**	**Flow (m^3/s)**	**Dmax (mm)**	**Dmin (mm)**
Ca-E	Water cannon	0.025	178.41	100
E-P4	Fire hydrant	0.017	145.67	100
C-R	AFV	0.0025	56.42	30.16

The bounds of the allowable diameter interval of the pipelines supplying each of the water points, calculated with the formulas (7), are grouped in Table 4.

Intersection of the intervals of the $Ca - E$ and $E - P4$ sections give:

$$I = [100;\ 145.67] \cap [100; 178.41] \quad (25)$$

$$I = [100; 145.67]$$

Consulting the HDPE pipe catalogs, the marketed pipes with an inside diameter between the bounds of the interval I are those with outside diameters 125; 140 et 160 mm.

The Ø=125 mm diameter pipe was selected as the pipe for the secondary sections feeding the fire hydrant and the water cannon and then the Ø=40 mm pipe for the section feeding the RIA.

3.1.2. Main line

Table 5 groups the maximum flow rates for each pipe size and the maximum number of equipment it can supply simultaneously. This table shows that a maximum of 125 mm diameter pipe can only be used to supply the water cannon and the fire hydrant simultaneously. The 140 mm diameter pipe, on the other hand, can only support the simultaneous supply of two fire hydrants in addition to the RIA. The plant opts for pipes of diameter Ø=140 mm.

Table 5 Pipe supply capacity

	No. of fire hydrants	**No. of water cannons**	**No. of RIAs**	**Cumulative flow (m^3/h)**	**Corresponding pipe diameter**
Possibility 1	1	0	1	69	125 ; 140; 160; 180 *et* 200
Possibility 2	0	1	1	99	125 ; 140; 160; 180 *et* 200
Possibility 3	2	0	0	120	140; 160; 180 *et* 200
Possibility 4	2	0	1	129	140; 160; 180 *et* 200
Possibility 5	1	1	0	150	160; 180 *et* 200
Possibility 6	1	1	1	159	160; 180 *et* 200
Possibility 7	3	0	1	189	180 *et* 200
Possibility 8	2	1	0	210	180 *et* 200
Possibility 9	4	0	0	240	200
Possibility 10	4	0	1	249	200

The network is then made with:

- stainless steel pipes of diameter ϕ 150 mm for the pump suction;
- stainless steel pipes of ϕ 125 mm for a length of 68.3 m for the apparent portion of the pump delivery pipes;
- HDPE pipes of 125 mm diameter for the secondary sections over a length of 184.96 m;
- 140 mm HDPE pipes for the main section for a length of 625.25 m;
- 40 mm HDPE pipes for the supply of the RIA for a length of 59 m.

3.1.3. Pressure losses

The calculation of the pressure losses was done in the cases of the supply of the water point generating the most pressure losses. If the pump is able to supply the pressure required for this point, it will be able to supply the other water points in the network without difficulty.

The water point whose supply generates the most pressure loss is the water cannon. In fact, in addition to being the water point geometrically furthest from the pump, the water cannon is the water point with the greatest number of singularities (elbows, tee connections) on the pipe that feeds it. Its supply is therefore the one that generates the most linear and singular pressure losses in the network. Moreover, it is the water point that delivers the highest pressure ($3.5\ bars$).

The constants used to calculate the linear and singular pressure losses are given in Table 6. The values of these losses found are grouped in table 7.

As the Reynolds numbers are all higher than 10,000, the linear pressure drop coefficients have been calculated with formula 16.

Table 6 Pressure drop calculation constants

Constants	**ε(PEHD) mm**	**ε(inox) mm**	**L(PEHD 140)**	**L(inox)**	**ν(eau)**
Values	0.02	0.015	$625.258\ m$	$625.258\ m$	$10^{-6}\ m^2/s$

Table 7 Linear, singular and total pressure losses

	Inside diameter (m)	**Reynolds number**	**Linear pressure drops (J/Kg)**	**Singular pressure drops (J/Kg)**	**Total pressure drops (J/Kg)**
Stainless steel	0.1172	271595.466	0.765315944	0.159461822	0.924777765
HDPE 140	0.1194	266591.1945	94.36854375	0.221282021	94.58982577

The calculated linear pressure losses amount to 0.765 J/Kg in the stainless-steel piping and 94.37 J/Kg in the HDPE one. On the section of the network going from the source to the water cannon, there are twelve elbows, six of which are on the stainless-steel portion (four at 45° and two at 90°) and five tee fittings. The singular pressure drops are 0.159 J/Kg in the stainless-steel piping and 0.221 J/Kg in the HDPE 140 piping. The pressure drops in the entire circuit, sum of the total pressure drops according to each piping, amount to 95.51 J/Kg or 0.955 bar.

3.2. Result of the water point modeling

In the case of the water cannon supply, replacing the constants in Table 8 in Formula 15, we find that the pump must supply at least 4.69 bars to properly supply the water cannon.

Table 8 Constants used to calculate the pressure to be supplied by the pump

Constants	P_2	ρ	z_2	z_1	g	V_2	V_1
Values	$350\ 000\ Pa$	$1000\ Kg/m^3$	$4100\ mm$	$2911\ mm$	$9.8\ m/s^2$	$3.04\ m/s$	$2.31\ m/s$

3.3. Result of the Diesel Pump Modeling

In order to determine the operating point of the pump, let's represent the characteristic curves of the pump and the network on the same graph using Excel software.

By analyzing this graph, the point of intersection of the characteristic curves has the coordinates: (218;56). Thus, for this network, the pump delivers a pressure of 56 m (i.e., 5.6 bars) for a flow rate of 218 m^3/h.

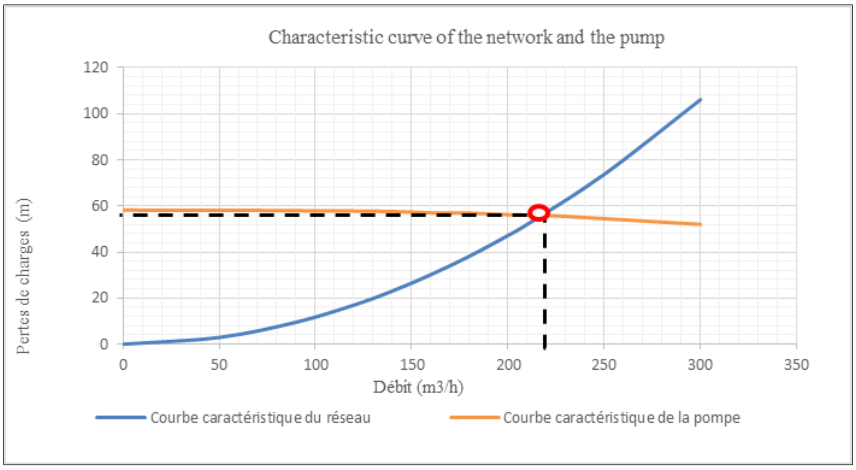

Figure 2 Characteristic curves of the network and the pump

3.4. Result of the cavitation study

The linear and singular pressure drops at the pump suction are 9 m and 0.313 m respectively. The total pressure drop is therefore 9.313 m. When the water cannon is fed, an available NPSH of 6.38 m is found at the suction with this pressure drop.

3.5. Result of the water reserve modeling

According to the sizing performed above, the selected main line allows to supply both two fire hydrants and the armed fire valve. This requires a cumulative flow rate $Q_{cu} = 129\ m^3/h$ and therefore a water reserve with at least a volume $V = 258\ m^3$.

4. Discussion

4.1. Network pipes

The main pipe of the network has a diameter of 140 mm. analyzing the table, it can be seen that the larger diameter pipes offer supply possibilities for unlikely fire cases such as those where the whole area covered by the network is on fire. These situations are not realistic and the use of the fire system will have no major effect on the fire. This main line will simultaneously supply the fire hydrant and two fire hydrants.

The diameter of the apparent portion of the network is equal to that of the pump discharge port. This consideration was made based on the following criteria:

- this portion is directly connected to the pump;
- the use of stainless steel with a diameter of 140 mm along the length of the apparent portion is more expensive than that of diameter 125 mm.

The network is then made with:

- stainless steel pipes of diameter ϕ 150 mm for the pump suction;
- stainless steel pipes of ϕ 125 mm for a length of 68.3 m for the apparent portion of the pump delivery pipes;
- HDPE pipes of 125 mm diameter for the secondary sections over a length of 184.96 m;
- 140 mm HDPE pipes for the main section for a length of 625.25 m;
- 40 mm HDPE pipes for the supply of the RIA for a length of 59 m.

4.2. Analysis of pressures and flows in the network

4.2.1. Supply of the water points

In the case of the supply of the point generating the most pressure losses, the motor-driven pump provides a pressure of 5.6 bars and a flow rate of 218 m^3/h, while the network requires at least a pressure of 4.59 bars at a flow rate of 90 m^3/h. The motor pump is therefore able to supply each of the various water points adequately.

The selected main line is able to supply both two fire hydrants and the armed fire valve. The motor-driven pump provides a flow rate greater than the flow rate required to supply two fire hydrants and the fire hydrant simultaneously. The pump is then capable of supplying two fire hydrants and the fire hydrant at the same time.

4.2.2. Protection of the network

The flow rate supplied by the pump is largely superior to the maximum flow rate that can pass through each of the main and secondary pipes. This leads to flow velocities in the pipes that exceed the upper limit of permissible velocity. In order to stay within the speed limit, a flow limiter was used. The flow rate in the main pipes was therefore set at 141 m^3/h , which corresponds to a speed of 3.5 m/s.

In addition, when the motor pump is operated with all the water points closed, there is overpressure and backflow of water. This backflow of water once in the pump damages the motor. A non-return valve is placed on the pump discharge to prevent the backflow from reaching the pump. In order to protect the pipes and especially the pump from overpressure, a pressure limiter set at 12 bars has been installed on the discharge side.

4.2.3. Installation of the pump

The dimensioning of the water reserve shows that it must have a volume of at least 258 m^3. The decanter of the plant with a volume of about 2000 m^3 was chosen to serve as a water reserve for the network.

In order to facilitate the suction of water and the priming of the pump, it is advisable to install the motor pump as close as possible to the water reserve. Due to flooding in the immediate vicinity of the decanter during the rainy season, the motor pump was moved away from the decanter. This resulted in a long suction pipe and therefore high-pressure losses at the pump suction. The pump suction head must be high in order to overcome these pressure drops.

The total head is the sum of the suction and discharge heads of the pump. When the water cannon is fed, the suction head is approximately 9.3 m, leaving a discharge head of 83.7 m, i.e., a pressure of 8.37 $bars$. This pressure is much higher than the pressure required to feed the water cannon. The long suction line does not prevent the motor pump from supplying the network adequately.

4.3. Cavitation and priming of the motor pump

Reading the curve of NPSH versus flow rate, provided by the manufacturer, gives for a flow rate of 218 m^3/h, a $NPSH_r = 2.1\ m$. By comparing the available and required NPSH, it can be concluded that the pump does not cavitate.

Priming is an operation that involves filling the pump with water to create a continuous column of water between the pump and the water tank. This makes it easier to pump water when the pump starts. When the water column is emptied of water, the pump is said to be de-primed. To prevent this, a foot valve has been installed at the suction side of the pump.

Since no system is 100% reliable, it is a good idea to always prime the pump before starting it. The pump is primed by means of a water reserve mounted on the suction pipe. This water reserve is nothing more than a STOREX filled with an electric submersible pump already available at the water source. To prime the pump, simply open the STOREX valve and let the water flow into the suction pipe.

5. Conclusion

The objective of this study is to dimension and install a firefighting network. This network is composed of five fire hydrants, one RIA and one water cannon. The dimensioning of the said network consisted first of all in determining the diameter of the secondary and main pipes in addition to the pressure necessary to feed the network. It was chosen pipes with a nominal diameter of 140 mm for the main pipe and 125 mm for the secondary pipe. In a second step, the behavior of the diesel motor pump was studied. This consisted of determining the operating point of the motor pump, the coordinates of which provide information on the flow rate and the pressure supplied by the pump. From this study, it appears that the motor pump is able to provide the pressure and the flow rate necessary to supply both two fire hydrants in addition to the armed fire valve. From the analysis of the pressures and flows in the network, several measures were taken to protect the pump and the network pipes.

Compliance with ethical standards

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Disclosure of conflict of interest

This research work does not present any conflict of interest.

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