HYDRAULIC DESIGN OF COLD WATER CIRCUIT FOR AIR CONDITIONS SYSTEM IN THE RIVER SUPPORT PATROL VESSEL

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Abstract: The process of auxiliary systems ship design is based on the selection of materials and equipment of each of the auxiliary systems that attending the services of the ship as they are the bilge, ballast, drinking water, fuel consumption, air conditioning among others, the object of this work is the design of circulation of cold water to the climate control system in a Fluvial Support Patrol Vessel developed by the Direction of Research, Design and Innovation of COTECMAR, this work is intended to analyze the hydraulic calculation considering the different combinations of the factors involved in the process as such as the material of pipe, the pipe diameter, equivalent length, diameter of impeller pump and types of valves. We identified the optimal values through the appropriate selection of diameters, lengths and valves to minimize losses in the system given that these constitute one of the factors which deplete efficiency in a system (LEÓN & CRUZ, 2007). In this work were developed two designs of experiments, one to screening the process and find the most significant factors in the calculation of the losses total circulation of cold water circuit, and a second experiment of background to analyze the effects of factors and their optimal combinations to minimize the total losses in the system. Hydraulic calculations of the circulation of cold water circuit were developed in the Huid analysis software Pipe Flow Expert. Experimental data were processed in the statistical software STATGRAPHICS Centurion XV. In the same way in this work gets a matematical expression to predict the behaviour of total losses from the adjustment and the regression model of the collected dates in experiments carried out.

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Keywords: Estuary, circulation, residual currents, temperature and salinity gradients, forcings.

Resumen: El proceso de diseño básico de sistemas auxiliares de un buque se basa en la selección de los materiales y equipos de cada uno de los sistemas auxiliares que asisten los servicios del buque como lo son el achique, lastre, combustible, agua potable, aire acondicionado entre otros, el objeto de este trabajo es el diseño del circuito de circulación de agua fría para el sistema de climatización de un buque tipo patrullera de apoyo fluvial desarrollada por la dirección de investigación diseño e innovación de COTECMAR, en este trabajo se pretende analizar el cálculo hidráulico estudiando las diferentes combinaciones entre los factores que intervienen en el proceso como tales como el material de tubería, diámetro de la tubería, longitud equivalente, diámetros de impeler de la bomba, tipos de válvulas entre otros. Se determinaron los valores óptimos mediante la selección adecuada de diámetros, longitudes y válvulas para minimizar las perdidas en el sistema dado que estas constituyen uno de los factores que empobrecen la eficiencia en un Sistema(LEÓN & CRUZ, 2007). En este trabajo se desarrollaron dos diseños de experimentos, uno para tamizar el proceso y encontrar los factores más significativos en el cálculo de las pérdidas totales en el circuito de circulación de agua fría, y un segundo experimento de fondo para analizar los efectos de los factores y sus combinaciones óptimas para minimizar las pérdidas totales en el sistema. Los cálculos hidráulicos del circuito de circulación de agua fría fueron desarrollados en el software de análisis de fluidos Pipe Flor Expert. Los datos experimentales fueron procesados en el software estadístico STATGRAPHICS Centurión.

Palabras clave: Hidráulica, Chiller, Patrullera de rió, Pipe Flow Expert.

1. INTRODUCTION

There are various types ofrefrigeration units in design systems of air conditioning for naval vessels either compression or absorption being the compression the most used. In the case of the system of air conditioning of the Support River Patrol Vessel, designed and built in COTECMAR a compression refrigeration plant was used with chillers and fan coils units with cooling through a closed- circulation circuit of cold water, for the distribution of air in the accommodation area of the ship. In Figure 1 is possible to see the functionality of the system by the schematic design of the same.

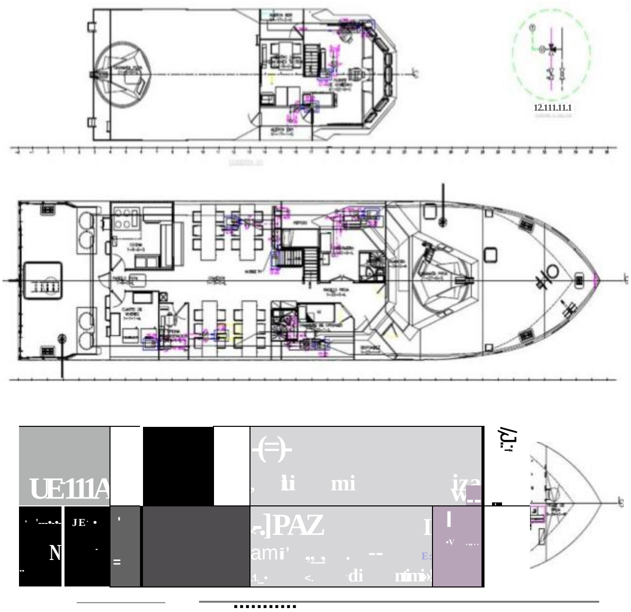

Figure 1. Schematic drawing of cold water circulation

In the basic design of the air-conditioning system in addition to the thermal load calculations that dimensioning the cooling unit, hydraulic calculations of circulating cold water circuit which is the subject of this work of experimentation is important(LINARES, 2007).

Different factors are involved in hydraulic calculations for water circulation circuits as the diameter of pipeline, the type of accessories and fittings used in the route which is represented by the equivalent length of the system, the material of the pipe, the type of valves, among others which allow to have an appropriate selection of the pump itself for such a system.

This experimentation aims to obtain the combination of diameter of impeller pump, pipe diameter pipe, accessories and valves that tolerate more variations of the system performing minor lost totals due to friction and the components of the system, in order to optimize the current design.

- The air conditioning system installed on board the ship is currently comprised of the following elements:

- A Chillers unit with rated capacity of 16 tons of refrigeration, condensation by water, formed by four compressors scroll type, two evaporators shell and tube type, four condenser tube-tube type with coolant R-134.

- A centrifuge pump for the movement of water cold IG-IHM model Euro-Line 3 x 18 with 180 mm of impeller diameter.

- Fourteen fan coil units with the following capacities; two units of 11400 btu/h, five of 17300btu/h and seven from 9000btu/h, distributed in the accommodation area of the ship.

An isometric view of the system can be seen in Figure 2.

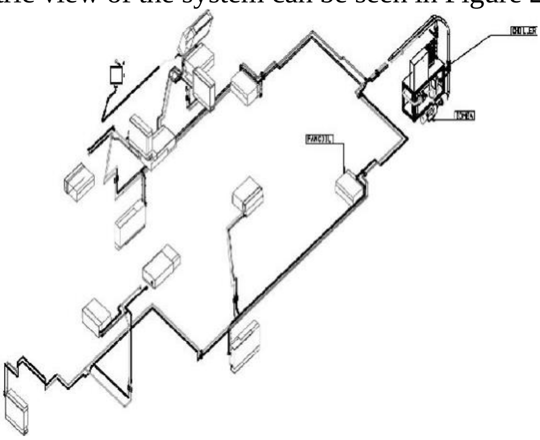

Figure 2. *The air conditioning system isometric view*

2 EXPERIMENTAL DE SIGN

2.1 Selection of the screening design

To carry out experimentation proceeded to make a first design factorial type by 25 for the procedure of screening which presents 32 experimental conditions. The factors of entry levels which were considered in this experimentation can be seen in the table 1:

Tabla 1: *Screening experiment input parameters*

Parameters	Symbol	Levels	
		Min	Max
Pipe Diameter (DN)	A	50	65
Diarnetro Impeler	B	129	152
Valves type	C	Butterfly	Gate
Long Eq	U)	3,87	5,03
Roughness Material	r	0,0015	0,046

Transported flow stood at 64 gpm which is the required flow for the functioning of the installed fan coils. Responses to analyze variables are: speed of the fluid and the total losses due to friction and pipe fittings. Experimentation will take place in the fluid analysis software Pipe Flow Expert, the experimental model does not include replies because the bullfights are developed software which does not have the natural variability of the process involved. Figure 3 presents the representation of the system in the fluid analysis software.

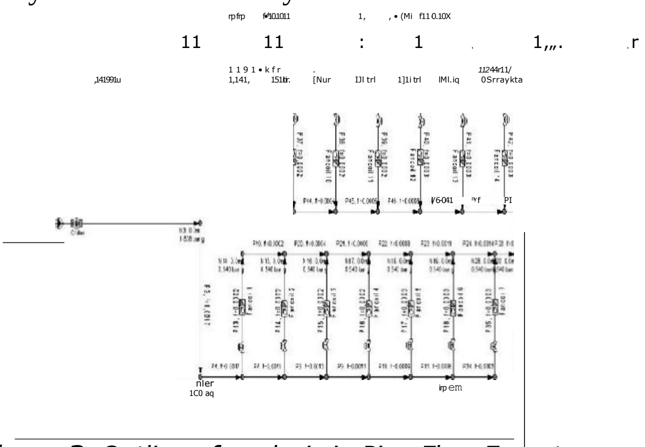

Figure 3. *Outline of analysis in Pipe Flow Expert*

2.2 Results of the screening design

Table 2 presents the results of the 32 experimental conditions associated with variables result.

Table 2: Experimentations results

A:Pipe diameter DN (mm)	B: Impeler (mm)	C:Valves	D:Long Eq k	E:Material (mm)	Speed m/s	Perdidas M
50	129	Buterfly	3,87	0,0015	2,076	6,866
65	129	Buterfly	3,87	0,0015	1,344	2,589
50	152	Buterfly	3,87	0,0015	2,076	6,866
65	152	Buterfly	3,87	0,0015	1,344	2,589
50	129	Gate	3,87	0,0015	2,076	4,994
65	129	Gate	3,87	0,0015	1,344	1,848
50	152	Gate	3,87	0,0015	2,076	4,994
65	152	Gate	3,87	0,0015	1,344	1,848
50	129	Buterfly	5,03	0,0015	2,076	9,767
65	129	Buterfly	5,03	0,0015	1,344	3,737
50	152	Buterfly	5,03	0,0015	2,076	9,767
65	152	Buterfly	5,03	0,0015	1,344	3,737
50	129	Gate	5,03	0,0015	2,076	7,895
65	129	Gate	5,03	0,0015	1,344	3,000
50	152	Gate	5,03	0,0015	2,076	7,895
65	152	Gate	5,03	0,0015	1,344	3,000
50	129	Buterfly	3,87	0,046	1,865	5,888
65	129	Buterfly	3,87	0,046	1,307	2,585
50	152	Buterfly	3,87	0,046	1,865	5,888
65	152	Buterfly	3,87	0,046	1,307	2,585
50	129	Gate	3,87	0,046	1,865	4,377
65	129	Gate	3,87	0,046	1,307	1,880
50	152	Gate	3,87	0,046	1,865	4,377
65	152	Gate	3,87	0,046	1,307	1,880
50	129	Buterfly	5,03	0,046	1,865	8,228
65	129	Buterfly	5,03	0,046	1,307	3,672
50	152	Buterfly	5,03	0,046	1,865	8,228
65	152	Buterfly	5,03	0,046	1,307	3,672
50	129	Gate	5,03	0,046	1,865	6,717
65	129	Gate	5,03	0,046	1,307	2,971
50	152	Gate	5,03	0,046	1,865	6,717
65	152	Gate	5,03	0,046	1,307	2,971

For the statistical analysis of the obtained experimentally values to employment the software STATGRAPHICS Centurion XV which was analysed each ofthe output ofthe variables process.

2.3 Analysis of the losses in the system

As you can see in Figure 4 the most significant variables for losses by pipe and accessories are the diameter of the pipe, the equivalent length of the system; in a second instance of significance are the type of valves, the roughness of the material of the pipe, the interaction of the diameter of the pipe and the equivalent length, the interaction of the diameter and material, and the interaction of the diameter of the pipe and the type of valves.

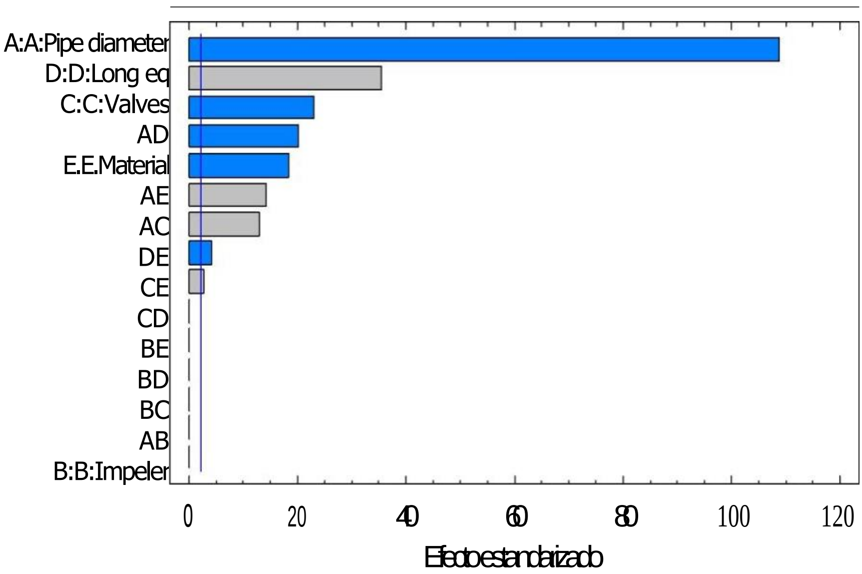

Figure 4. *Pareto diagram for the lost totals*

The significance of these factors and their interactions can be seen highlighted in red in the table III relevant to the analysis ofvariance for the system total losses dueto friction and accessories.

Table 3: Analysis of variance for total losse

Fuente	*Suma de Cuadrados*	*Gl*	*Cuadrado Medio*	*Razón-F*	*Valor-P*
A:A:Pipe diameter	131,625	1	131,625	11843,43	0,0000
B:B: Impeler	0,0	1	0,0	0,00	1,0000
C:C:Valves	5,85474	1	5,85474	526,80	0,0000
D:D:Long eq	14,0354	1	14,0354	1262,88	0,0000
E:E:Material	3,71426	1	3,71426	334,20	0,0000
AB	0,0	1	0,0	0,00	1,0000
AC	1,88374	1	1,88374	169,50	0,0000
AD	4,506	1	4,506	405,44	0,0000
AE	2,25356	1	2,25356	202,77	0,0000
BC	0,0	1	0,0	0,00	1,0000
BD	0,0	1	0,0	0,00	1,0000
BE	0,0	1	0,0	0,00	1,0000
CD	0,000008	1	0,000008	0,00	0,9789
CE	0,0788045	1	0,0788045	7,09	0,0170
DE	0,193442	1	0,193442	17,41	0,0007
Error total	0,177821	16	0,0111138		
Total (con.)	182,73	31			

Justas in Figure 5 can be seen the main effects of each of the factors on the total loss, each of the lines indicates the change estimated in losses according to each factor (diameter of pipe, type ofvalves, pipe materials and equivalent length) is moved below its upper level. Of the main effects graphic notes that as the diameter of the pipe increase the losses diminish and as the equivalent length increases the losses in the system also increases.

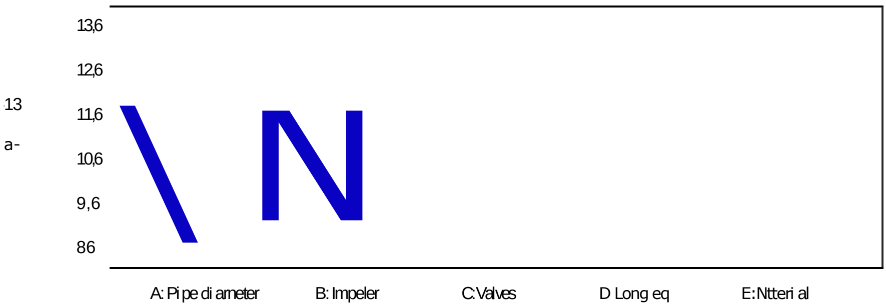

Figure 5: *Main effects for total loss drawing*

2.4 Analysis of the speed of the flow

The recommended speed of the fluid in a pipe for this kind of application should be between 1.5-3 m/s to maintain the allowable noise levels set for water in movement, as well as the effects of erosion in the pipes (CARRIER AIR CONDITIONING COMPANY).

In the experiment the diameter selected for the system have a speed within these ranges, as expected for a steady stream as diameter moves from the minimum value to its maximum value is decreased the speed, in the same way as the roughness of the material increases with the speed decreases; This can be seen in Figure 6 for the graphics of the main effects. Likewise you can see that the speed is not affected when moving values between the minimum and maximum of factors equal length, the diameter of the impeller pump and values type.

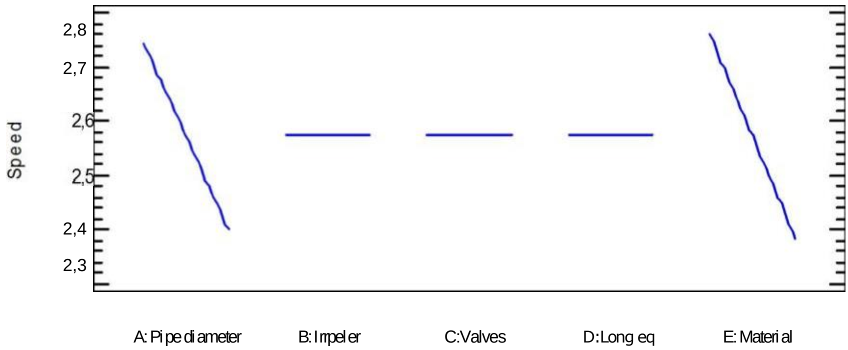

Figure 6: *Graph of Main effects*

In Figure 7 can be seen the factors that are significant to the speed of flow which are the type of material of the pipe, the diameter of the pipe and the second degree significantly, the interaction between these two factors.

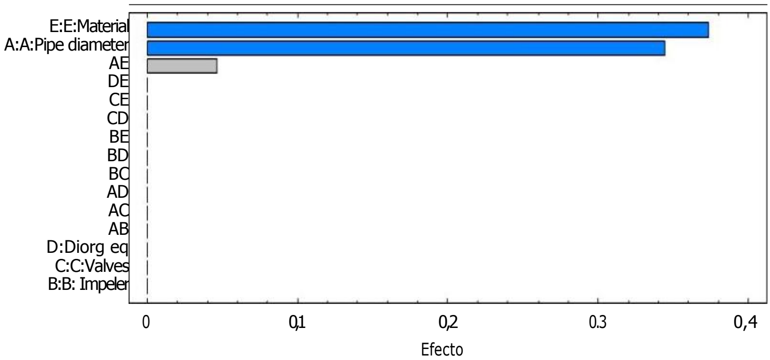

Figure 7. Pareto diagram for speed

The experiment of screening can be seen that the most significant variables in the process of the hydraulic circuit design of circulation of cold water to the air conditioning system are the material of the pipe, the diameter of the same, the equivalent length of the system and the type of valves. These factors are input to a second experiment of background which will allow us to make an approximate regression of the equation that governs the loss in the pipe.

2.5 Selection of the experimental background design

For the background experiment three levels of the factors that were most significant in the experiment of screening are analyzed, in the table IV can be seen used levels for the realization of the experiment factorial type 3^3 for a total of 27 experimental conditions and factors. Given that the size of the impeller pump is not significant that remains in 129 mm at this stage of the experiment. In the case of material of the pipe is a significant factor but because the use of materials with minor roughness such as polymers (PVC) is restricted in some marine applications depending on the fire rules to be used, for this stage of the experiment the roughness will be maintained in 0,0015 mm is the roughness for copper pipes to simplify a bit experimental conditions, and is more common to use copper pipes for this application.

The experimentation took place again in the Huid Pipe Flow Expert analysis software, and the results will be analyzed in the statistical software STATGRAPHICS Centurion XV.

Table 4: *The experiment of Fund input parameters*

Parameters	Svnibol	Lewis		
		Iin		Max
Pipe Dianieter (DN)	A	40	50	65
Lona Eq	B	3,87	5,03	7,05
Valves tepe	C	Buterfly	Gate	Ball

3 RESULTS AND DISCUSIÓN

Table 5 response of each of the carried out experimental conditions variables are appreciated.

Table 5: *Experimental Results*

A:Pipe diameter (mm)	B: Lon Eq m	C:Valves k	Speed m/s	Total Loss m
40	3,87	Butterfly	3,236	19,509
50	3,87	Butterfly	1,849	5,504
65	3,87	Butterfly	1,197	2,0732
40	5,03	Butterfly	3,236	3,800
50	5,03	Butterfly	1,849	6,947
65	5,03	Butterfly	1,197	2,6952
40	7,05	Butterfly	3,236	7,322
50	7,05	Butterfly	1,849	7,805
65	7,05	Butterfly	1,197	2,9841
40	3,87	Gate	3,236	4,578
50	3,87	Gate	1,849	4,019
65	3,87	Gate	1,197	1,4861
40	5,03	Gate	3,236	8,869
50	5,03	Gate	1,849	5,462
65	5,03	Gate	1,197	2,1082
40	7,05	Gate	3,236	2,391
50	7,05	Gate	1,849	6,319

65	7,05	Gate	1,197	2,3971
40	3,87	Ball	3,236	4,002
50	3,87	Ball	1,849	3,83
65	3,87	Ball	1,197	1,4071
40	5,03	Ball	3,236	8,292
50	5,03	Ball	1,849	5,274
65	5,03	Ball	1,197	2,0292
40	7,05	Ball	3,236	1,814
50	7,05	Ball	1,849	6,131
65	7,05	Ball	1,197	2,318

3.1 Analysis of total losses.

Figure 8 shows the most significant variables for total losses are the diameter of the pipe in its linear and quadratic component, equivalent length; a second grade of significance of the interaction between the material and the equivalent length of the system, as well as the type of valves and the interaction between the valves and the diameter is also significant in a second degree of importance.

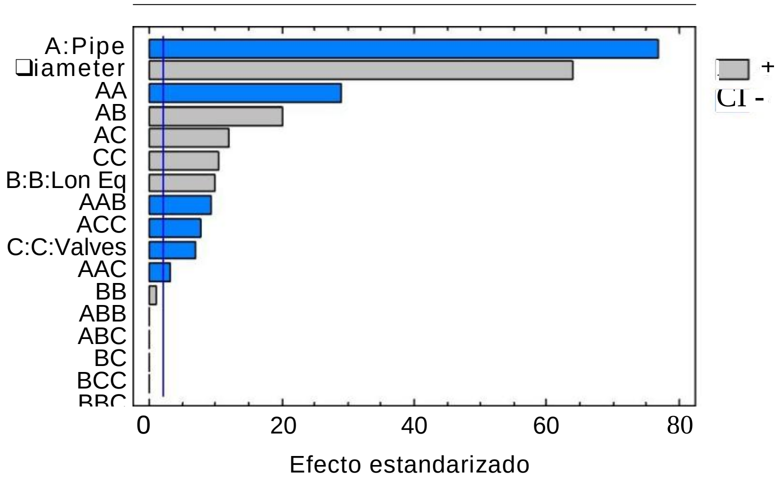

Figure 7: *Pareto diagram for total losses*

Total losses are diminished as the diameter of the pipe increases, and at the same time losses decline as the equivalent length of the system decreases, these effects are analysed and observed from Figure 8.

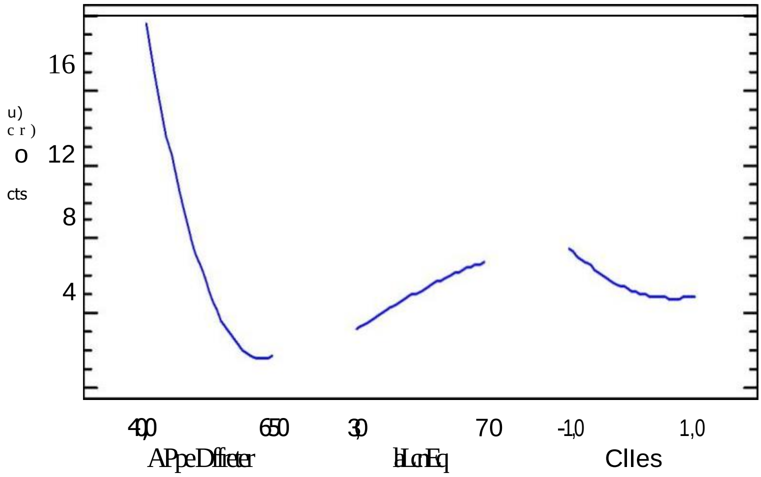

Figure 8: Graph of main effects

At the same time losses are diminished with the implementation of ball valves.

Verification of assumptions of normality par total missed wings can be seen from Figure 9

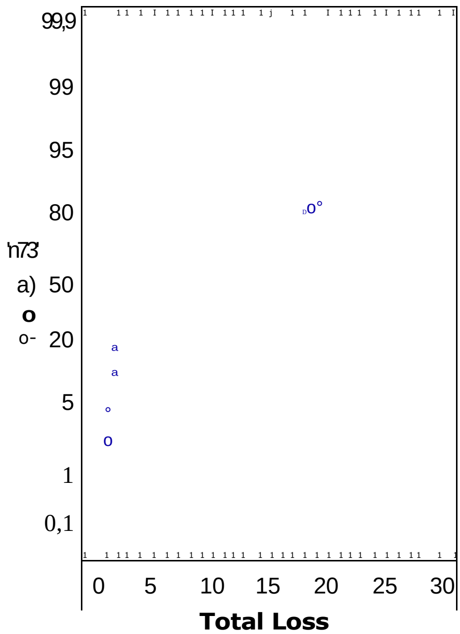

Figure 9: Graph of Normal Probability

Analysis of variance for the experimental results, which confirm the significance of the factors mentioned aboye for this process can be seen in table VI.

Table 6: *Analysis of variance for total losse*

Fuente	*Suma de Cuadrados*	*Gl*	*Cuadrado Medio*	*Razón-F*	*Valor-P*
A:A:Pipe Diameter	252,835	1	252,835	5890,96	0,0000
B:B:Lon Eq	4,7633	1	4,7633	110,98	0,0000
C:C:Valves	2,52071	1	2,52071	58,73	0,0000
AA	176,013	1	176,013	4101,04	0,0000
AB	35,7248	1	35,7248	832,37	0,0000
AC	17,5813	1	17,5813	409,64	0,0000
BB	0,474703	1	0,474703	11,06	0,0077
BC	8,33333E-8	1	8,33333E-8	0,00	0,9989
CC	6,3229	1	6,3229	147,32	0,0000
AAB	4,24841	1	4,24841	98,99	0,0000
AAC	1,99704	1	1,99704	46,53	0,0000
ABB	0,0474514	1	0,0474514	1,11	0,3178
ABC	1,25E-7	1	1,25E-7	0,00	0,9987
ACC	3,69857	1	3,69857	86,18	0,0000
BBC	2,77778E-8	1	2,77778E-8	0,00	0,9994
BCC	2,77778E-8	1	2,77778E-8	0,00	0,9994
Error total	0,429191	10	0,0429191		
Total (corr.)	1779,58	26			

3.2 Regression

Performing a regression non linear and constant equal to zero, the equation those best suits the analyzed process is given by the following expression:

$$\textbf{Total Loss} = 0{,}14\,A - 0{,}0012\,A^2 - 0{,}138\,AB + 8{,}22\,B$$

Where A is the pipe diameter **and B** is the equivalent length of the system. The correlation factors and total losses were verified for the regression. It also verified the significance of the coefficients of regression and the self regression. Regression introduced a regression coefficient of r^2 = 0,84 in Figure 10 you can observe the independence of the residual checking so this is regression model more successful for predicting total losses of the system.

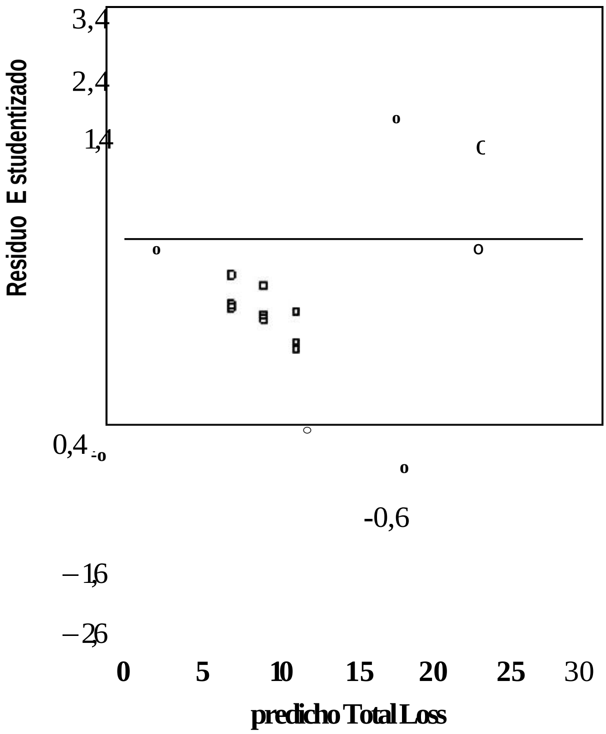

Figure 10: Graph of residual

3.3 Optimization

To minimize the total losses in pipe higher pipe diameters should be chosen and under equivalent length to a lower value of lost this can be seen in the graphic of contour surface of Figure 11, table VII are the combination of optimal