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BAGHOUSE SYSTEM DESIGN BASED ON ECONOMIC OPTIMIZATION

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Abstract. *In this study, a methodological approach for baghouse design based on economic optimization is developed in order to pursue the best compromise between surface area, pressure drop and filtration time for a given application. Fabric filters design parameters, in fact, are closely interrelated and affect system costs in counteracting manners, leading to possibility of cost minimization. In the paper, at first detailed cost functions are developed in order to obtain an overall economic model. Successively,the resulting objective function is adopted in order to define the optimal filter dimensions and operating parameters as a function of the stream characteristics, on the basis of total cost minimization. Finally, examples of optimized solutions are presented with reference to a set of different input data considering pulse-jet type fabric filters.*

Keywords*: Fabric filter, Economic analysis, Optimization.*

Nomenclature

A	Total filtering surface area (m^2)	ML	Maintenance labor cost ($/year)
AC	Operating annual cost ($/year)	ML_{HS}	Maintenance labor hours per shift (hr/shift)
B_L	Bag life (years)	ML_R	Maintenance labor rate ($/hr)
B_L^*	Bag life at reference face velocity (years)	MM	Maintenance materials cost ($/year)
B_{RT}	Bag replacement time (min)	N	Baghouse life (years)
B_S	Bag surface (m^2)	N_B	Bags number
C	Dust concentration (kg/m^3)	N_S	Number of daily shifts (shifts/day)
C_{ABR}	Annual bag replacement cost ($/year)	NC	Non-compliance cost ($/year)
C_B	Specific bag cost ($/m^2$)	OL	Operating labor cost ($/year)
C_{BR}	Bag replacement cost ($)	OL_{HS}	Operating labor hours per shift (hr/shift)
C_{BH}	Baghouse cost ($)	OL_R	Operating labor rate ($/hr)
C_{BT}	Total bag cost ($)	Q	Gas flow rate (m^3/s)
C_C	Cage cost ($)	S_e	Effective residual drag (kg/m^2 s)
C_{CA}	Compressed air annual cost ($/year)	SL	Supervisory labor cost ($/year)
C_E	Energy cost ($/kWh)	V_P	Permeation velocity (m/s)
C_I	Baghouse insulation cost ($)	V_P^*	Reference permeation velocity (m/s)
C_{TC}	Total cages cost ($)	t	time (s)
CA_B	Specific compressed air consumption (m^3/bag)	T_F	Filtration time (s)

CA_S	Compressed air cost (\$/hr per m^3/s of c.a.)	T_Y	Annual operating hours (hr/year)
d	Particle diameter (m)	TCI	Total capital investment (\$)
D_Y	Yearly operating days (days/year)	W_R	Residual dust load (kg/m^3)
E	Energy cost (\$/year)	ΔP_{BH}	Baghouse pressure drop (Pa)
i	Interest rate (%/year)	ε	Porosity
IDC	Indirect annual operating cost (\$/year)	η_F	Fan efficiency
K_F	Fabric specific resistance (kg/m^2 s)	μ	Gas viscosity (cP)
K_R	Residual dust cake specific resistance (s^{-1})	ρ_d	Dust density (kg/m^3)
K_{SR}	Dust cake specific resistance (s^{-1})	τ	Capital recovery factor (baghouse)
$M\&L$	Maintenance and labor expens (\$/year)	τ_B	Capital recovery factor (bags)

1. INTRODUCTION

Fabric filters performances are heavily affected by dust and fabric properties. Such properties are difficult to model analytically, and are peculiar of each specific application. Therefore, baghouse sizing is often performed in analogy with similar plants or resorting to experimental tests and pilot-plants, on the basis of empirical knowledge, of manufacturers proprietary data and of experienced designer's know-how. However, when specific information about the above mentioned parameters is available, the problem of fabric filter optimization may be faced analytically, at least in the preliminary design stage. At this stage, in fact, such an approach enables to establish the optimal overall plant arrangement, under the cost point of view, as well as to evaluate the relative effects of design choices, such as the adoption of alternative bag materials having different life and cost, and to screen among different designs and control equipments (Caputo et al., 1997). This also enables to compare the obtained results with the requirements dictated by specific site conditions or with the design parameter values (such as permeation velocity) suggested by empyrical formulations (Turner et al., 1987a) or by experimental knowledge in consideration of factors other than costs, such as dust collection efficiency and effectiveness of bag cleaning (Bustard et al., 1992a; Frankenburg, 1987; Jensen, 1989; Klimczak et al., 1997; Witt, 1992). Successively, in the detailed design phase, a complete modeling involving both fluid dynamic, cleaning mechanics and baghouse architecture considerations may be pursued in order to finely optimize the design and operational parameters. This latter phase has to be necessarily carried out resorting to much more detailed simulation approaches, like the ones already existing in the literature (Caputo et al., 1999; Dennis, 1979; Lu, 1996; Makino, 1980; Nierman, 1996; Schmidt, 1991; Turner et al., 1987a) which otherwise would be of limited applicability and usefulness if adopted in the preliminary design phase.

In this study, a methodological approach for baghouse design based on total cost minimization is developed in order to pursue the best compromise between filtration area, pressure drop and filtration time for a given fabric material.

Fabric filters design parameters, in fact, are closely interrelated and affect system costs in counteracting manners, leading to possibility of cost minimization:

- Filtration area affects capital investment and bags replacement costs, but its reduction leads to an increased permeation velocity which results in higher pressure drop and reduced bag life.
- The average pressure drop impacts on operating costs. Reduced pressure drop enables savings in energy expenses, but a reduced filtration time is required leading to higher maintenance and cleaning costs. A lower pressure drop may be also maintained by increasing the filtering area, but bearing higher capital and bag replacement expenses.
- Working time reduction penalizes operating expenses. It leads to increased energy requirements for frequent cleaning and accelerated bag wear. Moreover, a loss in average efficiency follows, the reduced dust cake itself being the primary filtering medium.

As a consequence, both permeation velocity and filtration time appear to be the two main design parameters affecting the total system cost. In the paper, detailed cost functions are developed in order to obtain an overall economic model. Successively, an objective function is defined in order to select the optimal filter dimensions and operating parameters as a function of the stream characteristics on the basis of total cost minimization. Finally, an example of optimized solutions is presented with reference to a wide range of design input data. In the paper specific reference is made to pulse-jet type fabric filters due to their compactness, lower cost and increased operating flexibility compared to other types, resulting a preferred choice in most aplications (Belba, 1991; Belba et al., 1992; Bustard et al., 1992b; Bustard et al., 1992c; Dean, 1988). However, the developed optimization model is of general application and few changes are required to take into account different kinds of fabric filters.

2. DEVELOPMENT OF FABRIC FILTER COST FUNCTION

Fabric filter cost functions are developed on the basis of the standard approach of Turner et al. (1987b).

2.1 Total capital investment

Filter cost depends essentially on the filtering surface area, A (m^2), determined from the actual flow rate to be cleaned, Q (m^3/s), and the average velocity, V_P (m/s), of the gas stream permeating through the filtering bag (often defined as "face velocity")

$$A = \frac{Q}{V_P} \tag{1}$$

In fact, the total capital investment, TCI ($), including installation, instrumentation and auxiliaries, plus taxes and freight may be expressed as

$$TCI = 2.56\,(C_{BH} + C_I + C_{BT} + C_{TC}) \tag{2}$$

i.e. as the sum of the baghouse cost, C_{BH}, baghouse insulation cost, C_I, total bag cost, C_{BT}, and total bag cage cost, C_{TC}, all of which depend on the total filtering area as indicated in Table 1.

Table 1. Details of fabric filter capital cost functions.

Symbol	Parameter	Value	Notes
C_{BH} ($)	Baghouse cost	C_{BH} = 63727 + (A 106.3683) C_{BH} = 303404 + (A 80.1369)	A<9290 m^2 A>9290 m^2
C_I $)	Insulation cost	C_I = 4045 + (A 30.1661) C_I = 81150 + (A 9.2466)	A<9290 m^2 A>9290 m^2
C_{BT} ($)	Bags cost - total	$C_{BT} = C_B$ A	
C_{TC} ($)	Cages cost - total	$C_{TC} = N_B C_C$	
N_B	Bags number	N_B = A / B_S	
C_C ($)	Cage cost - single	C_C = 12.201 + (B_S 2.267)	Stainless steel

By substituting the numerical expression of Table 1 in Eq. (2), and explicitating the filtering area it follows that

$$TCI = K_1 + K_2\left(\frac{Q}{V_P}\right) \tag{3}$$

indicating that the capital investment, for a given gas flow rate, depends essentially on the permeation velocity value adopted by the designer. The full expressions for K_1 and the other design parameters groupings introduced throghout the paper are given in the appendix, except where otherwise indicated. The adopted symbols being defined in the Nomenclature section.

2.2 Operating expenses

Operating expenses depend on both the permeation velocity and the filtration time. In fact, consistent with the objective of expressing also the annual cost as an exclusive function of the two above cited design parameters, it should be noted that an increase of permeation velocity increases the average pressure drop thus incrementing the energy expenses. This may be counteracted by reducing the filtration time, i.e. increasing the frequency of cleaning cycles. Obviously, more frequent cleanings involve an accelerated bag wear, higher maintenance expenses and an increased consumption of compressed air. Furthermore, a loss in average efficiency follows which may be considered a non-compliance cost. In fact, immediately after each cleaning cycle an increased dust emission is generally observed before the dust cake, which is the primary filtering medium, is formed again.

Therefore, the following operating cost items may be considered:

a) Maintenance and labor expenses (*M&L*);
b) Bag replacement cost (C_{BR});
c) Energy cost for blower operation (*E*);
d) Cost of compressed air for filter cleaning (C_{CA});
e) Non-compliance cost (*NC*);
f) indirect costs (*IDC*).

a) Maintenance and labor expenses (M&L). Are the sum of labor cost (operating, maintenance and supervisory) and maintenance materials, expressed as

$$M\&L = [1.6\ (OL + ML + SL + MM)] \tag{4}$$

However, supervising labor, *SL*, may be expressed as a fraction of operating labor, *OL*, while maintenance materials, *MM*, may be put equal to maintenance labor, *ML*, as indicated in Table 2, resulting in

$$M\&L = 1.33\ OL + 3.2\ ML. \tag{5}$$

OL and *ML* are usually expressed in terms of hours/shift, OL_{HS} and ML_{HS}. Further, the incidence of maintenance labor may be made proportional to the frequency of cleaning cycles, to account for the wear of equipment, which may be considered proportional to the utilization factor. In this case, indicating with T_F^* the filtration time corresponding to the reference bag life in average operating conditions it follows, after substitution in Eq. (5) of the numerical value indicated in Table 2 that

$$M\&L = K_3 + K_4\left(\frac{T_F^*}{T_F}\right)^{0.6} \tag{6}$$

Table 2. Maintenance and labor cost functions.

Symbol	Parameter	Value
OL ($/year)	Operating labor cost	$OL = D_Y N_S OL_{HS} OL_R$
ML ($/year)	Maintenance labor cost	$ML = D_Y N_S ML_{HS} ML_R (T_F^*/T_F)^{0.6}$
MM ($/year)	Maintenance materials cost	MM = ML
SL ($/year)	Supervising labor cost	SL = 0.15 OL

b) Bag replacement cost (C_{BR}). Bag replacement expense, C_{BR}, occurs at the end of bags life and is composed of replaced bags cost plus replacement labor cost:

$$C_{BR} = \frac{ML_R\, 1.6\;\, A\;\, B_{RT}}{B_S\; 60} + 1.08\, AC_B = \frac{ML_R\, 1.6\;\, Q\;\, B_{RT}}{V_P\;\, B_S\;\, 60} + \frac{1.08\, Q\, C_B}{V_P} = K_5\,\frac{Q}{V_P} \tag{7}$$

where B_{RT} is the bag replacement time, B_S the bag surface and M_{LR} the maintenance labor rate. During the entire baghouse life the whole set of bags is likely to be replaced several times. This periodic expense may be regarded as a repeated investment that can be uniformly distributed over the plant life if it is expressed in terms of an equivalent annual bag replacement cost, C_{ABR}:

$$C_{ABR} = \tau_B\, K_5\, \frac{Q}{V_P} \tag{8}$$

by introducing a bag capital recovery factor τ_B, computed over bag life B_L,

$$\tau_B = \frac{i\,(1+i)^{B_L}}{(1+i)^{B_L} - 1} \tag{9}$$

being i the interest rate. However, for a given stream and bag material, bag life may be considered dependent on the severity of cleaning action which leads to accelerated bag wear. Indirectly, it may be also correlated to the permeation velocity. In fact, an increased permeation velocity results in higher cleaning frequency when a given pressure drop is to be maintained, due to the accelerated dust cake build-up. Chapman et al. (1980) correlate bag life only to permeation velocity. However, by explicitly adding the effects of cleaning cycle frequency to their correlation, the following expression is obtained:

$$B_L = B_L^*\left(\frac{V_P^*}{V_P}\right)^{0.6}\left(\frac{T_F}{T_F^*}\right)^{0.4} \tag{10}$$

where B_L^* is bag life at a specified permeation velocity value V_P^*.

As a consequence, the bag replacement cost may be assumed as dependent on permeation velocity and filtration time or cleaning cycles frequency. However, it should be noted that early attempts to directly correlate bag life to cleaning frequency failed to give reliable results (Felix et al., 1990) and further research work is needed, even if such a dependence is plausible indeed.

c) Energy cost for blower operation (E). It depends on the overall baghouse pressure drop. Tubesheet pressure drop in a single bag depends, in turn, from permeation velocity, filtration time and dust-fabric related properties such as the effective residual drag S_e and cake specific resistance K_{SR}:

$$\Delta P = (S_e\, V_P) + (K_{SR}\, C\, V_P^2\, t) \tag{11}$$

where t is time, C the dust concentration in the gas stream and V_P the permeation velocity. Residual drag, is usually measured experimentally. Several different approaches to estimate K_{SR} have been istead developed in literature (Dirgo et al., 1983; Endo et al., 1998; Happel, 1958; Leith et al., 1980; Miller et al., 1988). In order to estimate the average pressure drop in a multibag and multicompartment sequentially cleaned unit the effects of different cleaning cycles phasing should be accounted for, as they lead to continuous time variation of gas flow caused by the variations of total drag in the compartments. A rather tedious iterative procedure involving the simultaneous solution of the equation describing the drag growth in each compartment is thus required (Dennis et al., 1979; Makino et al., 1980; Nierman et al., 1996). Such a procedure does not lends itself to be formalized in closed form; further it is strictly dependent on specific design parameters, such as compartments number and cleaning sequences, preventing it to be utilized in an overall analytical optimization model. However, a rough estimate of average system pressure drop for a multibag system is also obtained by the following equation (Dennis et al., 1981):

$$\Delta P_{BH} = (S_e\, V_P) + (0.75\, K_{SR}\, C\, V_P^2\, T_F) \tag{12}$$

being T_F the filtration time, i.e. the interval between two successive cleanings of the same bag. Neglecting ductwork and baghouse casing intrinsic pressure drop, the energy consumption depends essentially from the average baghose pressure drop ΔP_{BH}:

$$E = [(1/\eta_F)\, \Delta P_{BH}\, Q\, T_Y\, C_E] = K_6\, Q\, V_P + K_7\, Q\, V_P^2\, T_F \tag{13}$$

where η_F is fan efficiency, T_Y the number of annual operating hours and C_E the electricity cost.

d) Cost of compressed air for filter cleaning (C_{CA}). Usually this cost is grossly evaluated on the basis of the utility cost (hourly cost at a reference flow rate) and estimating the required compressed air flow rate according to the raw gas flow rate, assuming a specific compressed air consumption per unit gas flow rate. However, if a specific dependence of compressed air consumption with cleaning cycles frequency is sought, then the amount of air required to clean a single bag, CA_B (m^3/bag), can be considered. Indicating with CA_S ($/hr per m^3/s of compressed air flow rate) the specific cleaning air cost we get

$$C_{CA} = \frac{N_B\, CA_B}{T_F}\, CA_S\, T_Y = K_8 \frac{Q}{V_P\, T_F} \tag{14}$$

e) Non-compliance cost (NC). Such a cost does not directly correspond to a monetary cost. Rather, it is a figurative environmental cost connected to the increase of stack opacity due to frequent cleaning cycles. In fact, an increase of dust emissions is observed immediately after each cleaning cycle before the deposited dust cake, which is the primary filtering medium, is formed again. When the cleaning cycles frequency is increased a greater percentage of the overall operating time is characterized by incomplete dust cake formation and reduced filter efficiency. However, due to the very different and subjective manners that this cost may be accounted for it will be not be considered here any further.

f) Indirect costs (IDC). In case of fabric filters they may be assumed as a fraction of the total capital investment:

$$IDC = 0.04\, TCI = K_9 + K_{10}\left(\frac{Q}{V_P}\right) \tag{15}$$

2.3 Total annual cost function

Summation of cost items a) to f) leads to the following overall expression for annual cost, *AC* (\$/year):

$$AC = K_3 + K_4 \left(\frac{T_F^*}{T_F} \right)^{0.6} + K_5\, Q \left(\frac{\hat{o}_B}{V_P} \right) + K_6\, Q\, V_P + K_7\, Q\, V_P^2\, T_F + K_8 \frac{Q}{V_P\, T_f} + K_9 + K_{10} \frac{Q}{V_P} \quad (16)$$

The objective function to be minimized can be thus considered the Total Annual Cost (*TAC*, \$/year), which is computed on the basis of *TCI* and *AC*, but excluding bag replacement cost (C_{BR}) from the capital recovery as bag cost is already computed in operating costs:

$$TAC = AC + [(TCI - C_{BR})\ \tau] \quad (17)$$

τ being the baghouse capital recovery factor, computed as indicated in Eq. (9) but substituting the bag life B_L with the baghouse life *N*.

3. EXAMPLE OF OPTIMIZATION ANALYSIS

Resorting to Eqs. (3), (16) and (17) the total annual cost of a baghouse may be minimized with respect to the two variables V_P and T_F. However, it should be noted that this procedure leads to a strictly economic optimization. In fact, site specific conditions or different constraints connected to filter performances or dust properties may force the designer towards the adoption of economically sub-optimal designs. In any case, the results from economic optimization constitute an useful judgement factor.

In order to present a practical application of the developed approach a reference case study is analyzed. Adopting the design parameter values given in Table 3 (Reference case) and Table 4 to evaluate the system *TAC*, the effects of V_P and T_F on total annual cost have been computed as shown in Fig. 1. It is clearly shown as an optimal permeation velocity results for each specified value of the filtration time. For a given T_F, in fact, the increase of V_P at first decreases the total cost due to a reduction in capital investment, then the excessive dust cake accumulated during the filtration cycle leads to ever increasing pressure drop and energy cost which causes an overall increase of total cost progressively offsetting the previous advantage and leading to an optimal V_P. The optimal V_P increasing as the T_F decreases, an obvious consequence of the reduced average pressure drop which exalts the benefical size reduction effects. Given a V_P, instead, an optimal T_F may be found as a consequence of the balance between increased bag wear and maintenance expenses and the reduced pressure drop as T_F decreases. A detail of cost items for the reference case is given in Table 5. In order to show how different stream characteristics and design assumptions may modify the optimal values of the operating parameters, four other cases were considered for comparison with the base case as follows:

- #1 Adoption of a higher cost bag material (Teflon) having an extended bag life;
- #2 Adoption of a cheaper but short-lived bag material;
- #3 Filtration of a "difficult" stream characterized by high dust loading and high specific dust cake resistance;
- #4 Filtration of an "easy" stream having low dust loading and cake resistance.

Parameters values subjected to changes are shown in Table 3, while other parameters remained as indicated in Table 4. As an example, in the considered application the short life of the cheaper bag material appears to be more penalizing than the high cost of a more durable material, being the optimal T_F and V_P roughly the same. When comparing a "difficult" stream with an "easy" one, instead, the optimal permeation velocity shows small variation while the optimal filtration time is strongly different thanks to the smaller pressure drop increase when

V_P grows, which leads to lower total annual cost due to the significant savings obtained in cleaning expenses. This shows the high influence that stream characteristics may influence on baghouse design and cost.

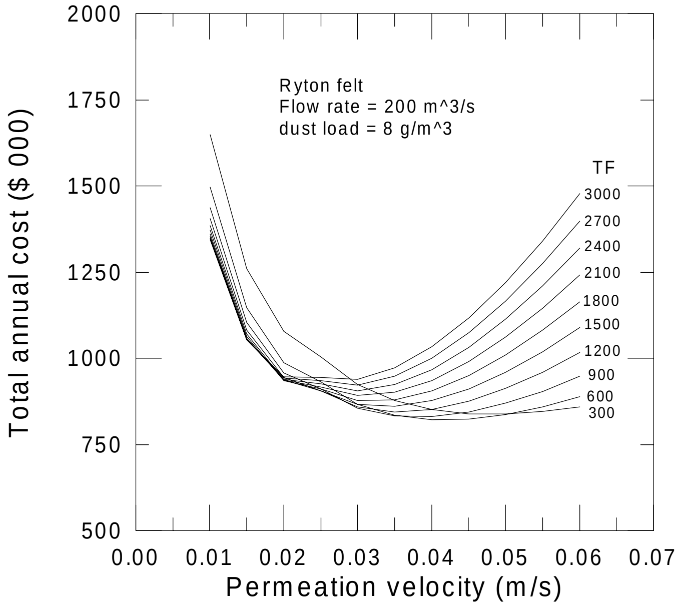

Figure 1 - Total annual cost optimization (reference case).

Table 3. Considered parameters variation.

Case	Q (m^3/s)	Bag material	B_L^* (years)	C_B ($\$/m^2$)	C (g/m^3)	K_{SR} (s^{-1})
Reference	200	Ryton felt	3	32	8	85000
#1	200	Teflon felt	5	110	8	85000
#2	200	Glassfiber	2	16	8	85000
#3	200	Ryton felt	3	32	15	140000
#4	200	Ryton felt	3	32	4	50000

Table 4. Adopted design parameters values.

B_{RT} (min)	7.5	i (%/year)	0.08	O_{LR} ($/hr)	14
B_S (m^2)	2.87	ML_{HS} (hr/shift)	1	S_e (kg/m^2 s)	37500
CA_B (m^3/bag)	0.02	M_{LR} ($/hr)	14	T_Y (operating hrs/year)	7440
CA_S ($/h per m^3/s)	50	N (years)	15	T_F^* (s)	900
C_E ($/kWh)	0.07	N_S (maint. shifts/day)	1	V_P^* (m/s)	0.02
D_Y (days/year)	310	OL_{HS} (hr/shift)	2	η_F	0.7

Table 5. Influence of optimization parameters on minimum system cost (reference case).

V_P *(m/s)*	T_F *(s)*	ΔP_{BH} *(Pa)*	*TCI* *($ 000)*	*M&L* *($ 000)*	*E* *($ 000)*	C_{ABR} *($ 000)*	C_{CA} *($ 000)*	*AC* *($ 000)*	*TAC* *($ 000)*
0.01	900	420.9	7533.017	25.4324	62.62992	192.5534	57.60743	639.5438	1436.591
0.01	2400	497.4	7533.017	19.25447	74.01312	140.6176	21.60279	556.8087	1353.855
0.015	900	665.775	5350.164	25.4324	99.06731	157.9635	38.40496	534.8748	1104.577
0.015	2400	837.9	5350.164	19.25447	124.6795	113.5465	14.40186	485.8889	1055.591
0.02	1800	1117.2	4258.737	20.70706	166.2393	108.2495	14.40186	479.9472	935.9775
0.025	1500	1415.625	3758.568	21.76627	210.645	103.6437	13.82578	500.2234	906.1223
0.03	1200	1675.8	3161.056	23.23069	249.359	103.1113	14.40186	516.5451	858.1724
0.035	900	1874.775	2734.262	25.4324	278.9665	106.78	16.45927	537.0087	832.7277
0.04	600	1989.6	2414.166	29.2575	296.0525	117.0059	21.60279	560.4852	821.7731
0.045	600	2307.15	2165.203	29.2575	343.3039	111.1393	19.20248	589.5112	824.0193
0.05	600	2640	1966.032	29.2575	392.8319	106.1672	17.28223	624.1802	837.2644
0.055	300	2525.325	1803.074	38.39243	375.7683	132.7289	31.42224	650.4349	845.9905
0.06	300	2800.8	1667.276	38.39243	416.759	127.9282	28.80372	678.5744	859.5228

Table 6. Comparison of case studies (optimal solutions).

Case	V_P *(m/s)*	T_F *(s)*	ΔP_{BH} *(Pa)*	*TCI* *($ 000)*	*M&L* *($ 000)*	*E* *($ 000)*	C_{ABR} *($ 000)*	C_{CA} *($ 000)*	*AC* *($ 000)*	*TAC* *($ 000)*
Reference	0.04	600	1989.6	2414.166	29.2575	296.0525	117.0059	21.60279	560.4852	821.7731
#1	0.045	600	2307.15	3052.67	29.2575	343.3039	233.7361	19.20248	747.6067	1042.056
#2	0.04	600	1989.6	2209.366	29.2575	296.0525	88.27242	21.60279	523.5598	771.0151
#3	0.04	300	2256	2414.166	38.39243	335.6928	152.0332	43.20558	665.8906	927.1785
#4	0.045	1200	2052	2165.203	23.23069	305.3376	85.82886	9.60124	510.6064	745.1145

4. CONCLUSIONS

A fabric filter design optimization method based on total cost minimization is presented in this paper. The model enables to determine the values of permeation velocity and filtration time which lead to the minimum total annual cost. The model shall be an useful support in the preliminary design phase when the overall plant arrangement is defined and the relative effects of design choices on total system cost are examined. As an example, the model enables to easily determine the optimal filtration time given a permeation velocity selected on the basis of specific dust and fabric properties. Moreover, it enables to evaluate alternative suitable fabric materials for a given application. Finally, it enables the comparison of fabric filters with other particulate control options during the screening phase of alternative solutions. However, a strictly economic optimization does not account for important design aspects connected to each specific application. Often, in fact, consideration of specific dust-fabric related issues will force towards sub-optimal choices under the economic point of view. In this case, however, utilization of the present model will constitute anyhow an useful decision support. Finally, it should be noted that the goodness of results obtained by utilizing this model depends heavily on the values given to the parameters incorporated in the model, which should be always supplied and evaluated by experienced designers.

APPENDIX

Following are the expressions of the various parameters groupings K_i introduced throughout the paper:

$K_1 = 173496.32$ $^{(°)}$	$K_5 = \frac{ML_R\, 1.6 \quad B_{RT}}{B_S\;\, 60} + 1.08\, C_B$
$K_1 = 984458.24$ $^{(°°)}$	$K_6 = (1/\eta_F)\, T_Y\, C_E\, S_E$
$K_2 = 355.331 + 2.560\, C_B + \frac{31.241}{B_S}$ $^{(°)}$	$K_7 = (1/\eta_F)\, T_Y\, C_E\, K_0$
$K_2 = 234.625 + 2.560\, C_B + \frac{31.241}{B_S}$ $^{(°°)}$	$K_8\, \frac{CA_B\, CA_S\, T_Y}{B_S}$
$K_3 = D_Y\, N_S\, (1.33\, OL_{HS}\, OL_R)$	$K_9 = 0.04\, K_1$
$K_4 = D_Y\, N_S\, (3.2\, ML_{HS}\, ML_R)$	$K_{10} = 0.04\, K_2$

(°) = (A < 9290 m^2) (°°) = (A > 9290 m^2)

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