고기집 '연기흡입덕트' 시공

덕트 형상 개선을 통한 비용 최소화

<냄새과 함께 사라지다>

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장성균

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Review of the Problem

- Design the geometry of duct and hood which can reduce material cost without any other additional cost, e.g. power consumption, purchasing of more powerful fan.
- The new duct shoud be operated at least the same performance of the exist one.
- Material cost is directly related to the surface area of the sheet metal.

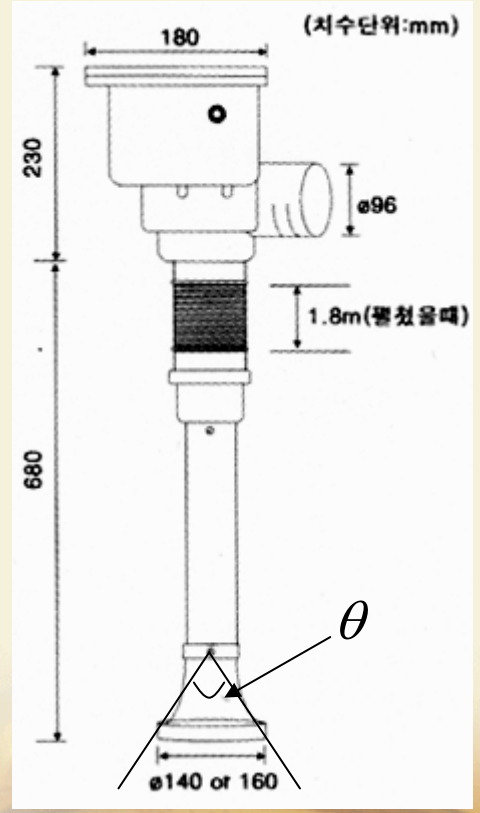
Data and Information Collection

- 덕트입구속도: $V_0 = 8.5$ m/s
- 점성계수: $\mu = 1.708 \times 10^{-5}$ kg/m·s
- 밀도: $\rho = 1$ kg/m^3
- 후드의 각도: $\theta = 16°$
- 후드입구의 마찰계수:

  $K = 0.0187$ ($\theta = 16°$일 때)
- 덕트 내부의 조도:

  $e = 0.15$ mm (아연도금강관)
- 아연도금강판(GI steel)의 가격:

  $W = 49{,}980$원/m^2

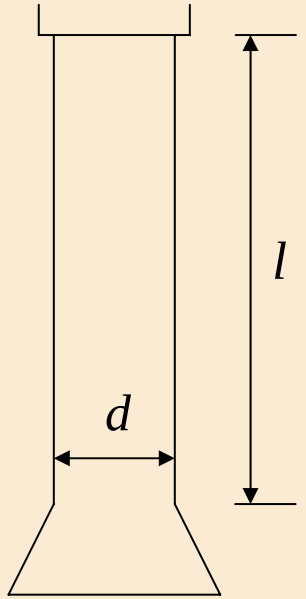


모델명	풍량 Q_0	후드 길이 L_0	덕트 길이 l_0	후드 지름 D_0	덕트 지름 d_0	정압 p_0
PC140F	240 ㎥/h	135 mm	776 mm	140 mm	100 mm	23 mmAq

(출처: 다나와공구)

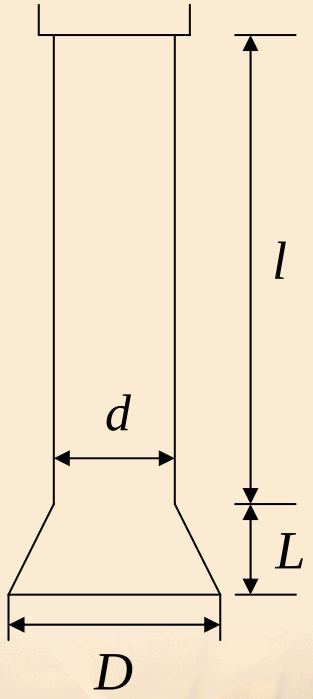
Design Variables

- d : diameter of the duct (m)
- l : length of the duct between hood and ceiling (m)



Design Variables

- d : diameter of the duct (m)
- l : length of the duct between hood and ceiling (m)
- D : diameter of the hood (m)
- L : height of the hood (m)



Cost Function

- Total surface area of the sheet metal

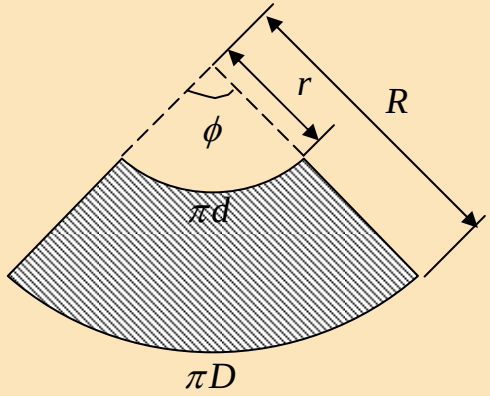
$$\underset{d,\,l}{\text{Minimize}}\ f = \pi dl$$

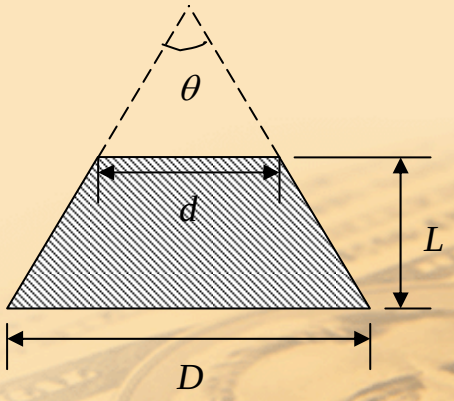
Cost Function

- Cost of GI steel

$$\underset{d,\,l,\,D,\,L}{\text{Minimize}}\ f = \left(\pi dl + \frac{D^2 - d^2}{\pi \sin\frac{\theta}{2}} \right) W$$

$$\text{where} \quad \theta = 2\tan^{-1}\left(\frac{D-d}{2L} \right)$$





Constraints

$$g_1 = -\frac{\pi}{4} d^2 V_0 + Q_0 \le 0$$

$$g_2 = p \cdot Q - Z_P \le 0$$

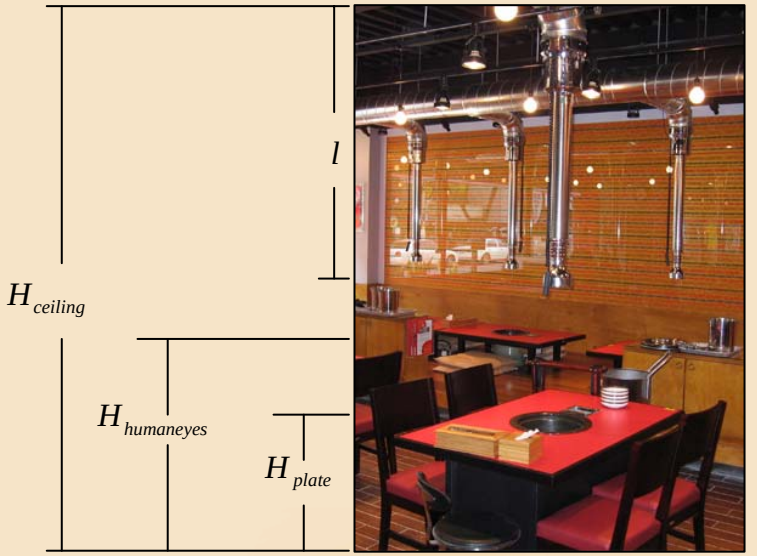
$$= \left\{ \rho g \left(h_L + h_m \right) \right\} \cdot \frac{\pi}{4} d^2 V_0 - Z_P \le 0$$

where $h_L = 0.0055 \left[1 + \left(20000 \frac{e}{d} + \frac{\mu \cdot 10^6}{\rho V_0 d} \right)^{\frac{1}{3}} \right] \frac{V_0^2}{2g} \frac{l}{d}$

$$h_m = K \frac{V_0^2}{2g}$$

$$g_3 = l - H_{ceiling} + H_{humaneyes} \le 0$$

$$g_4 = H_{ceiling} - l - H_{plate} - L_{regular} \le 0$$



Constraints

$$g_1 = 60 \times 14.5 \times \left[H_{ceiling} - \left(l + L + H_{plate} \right) \right]^{1.8} \times D^{0.2} \times V_c - Q_0 \le 0$$

$$g_2 = (p_L + p_m) - p_0 \le 0$$

$$\text{where} \quad p_L = 0.0055 \left[1 + \left(20000 \frac{e}{d} + \frac{\mu \cdot 10^6}{\rho V_0 d} \right)^{\frac{1}{3}} \right] \frac{l}{d} \frac{V_0^2}{2g} \rho g$$

$$p_m = K \frac{V_0^2}{2g} \rho g$$

$$g_3 = \theta \le 179^\circ$$

$$= 2 \tan^{-1} \left(\frac{D - d}{2L} \right) \le 179^\circ$$

$$g_4 = d - D + 0.001 \le 0$$

$$d,\ l,\ D,\ L \ge 0$$

Optimization with SQP

프로그램 실행 화면

```
>> x0=[0.01 0.5 0.5 0.1];

>> A=[1 0 -1 0];
>> b=0;

>> options = optimset('LargeScale','off','MaxIter',100,'Display','iter');
>> [x,fval,exitflag,output] = fmincon(@op_project3_objfun,x0,A,b,[],[],[0 0 0 0],[],@op_project3_nonlin,options)
```

Optimization with SQP

결과

Max Iter	F-count	f(x)	Line search constraint	steplength	Directional derivative	First-order optimality	Procedure
0	5	5079.19	3420				Infeasible start point
1	10	15507	787.1	1	1.49e+004	2.97e+005	
2	15	14386.5	36.95	1	-723	1.19e+005	
3	20	12550.9	36.56	1	-1.73e+003	3.83e+005	Hessian modified
4	25	12695.8	9.533	1	1.29e+003	6.5e+003	
5	30	12130.9	2.487	1	-206	1.04e+004	
6	35	12309	0.6373	1	218	2.27e+003	
7	40	12441.3	0.1512	1	141	2.67e+003	
8	45	12504.7	0.02693	1	63.9	1.48e+003	
9	50	12522.1	0.001823	1	17.5	407	
10	55	12523.4	1.772e-007	1	1.36	88.1	
11	60	12523.4	0	1	-0.00178	8.83	
12	65	12523.4	0	1	-0.00214	0.126	
13	70	12523.4	0	1	-1.3e-007	0.000388	Hessian modified

Optimization terminated: magnitude of search direction less than 2*options.TolX
and maximum constraint violation is less than options.TolCon.
Active inequalities (to within options.TolCon = 1e-006):

lower	upper	ineqlin	ineqnonlin
		1	
		2	
		9	

Optimization with SQP

결과

```
x =
    0.0223    3.5609    0.0550    0.0275

fval =

  1.2523e+004

exitflag =

     4

output =

       iterations: 13
        funcCount: 70
     lssteplength: 1
         stepsize: 9.3024e-009
        algorithm: 'medium-scale: SQP, Quasi-Newton, line-search'
    firstorderopt: 1.3543e-004
          message: [1x142 char]

theta_final =

   61.5594

Height =

    0.0165
```

Optimization with GA

Problem Setup and Results

Fitness function: @op_project3_objfun

Number of variables: 4

Constraints:

Linear inequalities: A = [1 0 -1 0] b = 0

Linear equalities: Aeq = beq =

Bounds: Lower = [0 0 0 0] Upper =

Nonlinear constraint function: @op_project3_nonlin

Plots

Plot interval: 1

☐ Best fitness ☐ Best individual ☐ Distance

☐ Expectation ☐ Genealogy ☐ Range

☐ Score diversity ☐ Scores ☐ Selection

☐ Stopping ☐ Max constraint

☐ Custom function:

Run solver

☐ Use random states from previous run

Start Pause Stop

Current generation: 7

Status and results: Clear Status

```
------------------------------
GA running.

GA terminated.
Fitness function value: 12526.600359717064
Optimization terminated: average change in the fitness value less than options.TolFun
 and constraint violation is less than options.TolCon.
```

Final point:

1	2	3	4
0.02228	3.56597	0.04426	0.02212

결과

d=0.02228

l=3.56597

D=0.04426

L=0.02212

f=12526.6

Optimization with PS

Problem Setup and Results

Objective function: @op_project3_objfun

Start point: [0.06 1 0.5 0.5]

Constraints:

Linear inequalities: A = [1 0 -1 0] b = 0

Linear equalities: Aeq = beq =

Bounds: Lower = Upper =

Nonlinear constraint function: @op_project3_nonlin

Plots

Plot interval: 1

☐ Best function value ☐ Mesh size ☐ Function count

☐ Best point ☐ Max constraint

☐ Custom function:

Run solver

Start | Pause | Stop

Current iteration: 6

Status and results: Clear Status

```
------------------------------
Pattern search running.
Warning: Divide by zero.Warning: Divide by zero.
Pattern search terminated.
Objective function value: 12762.322878358182
Maximum number of function evaluations exceeded: increase options.MaxFunEvals.
```

Final point:

1	2	3	4
0.0227	3.57682	0.0227	0.01116

결과

d=0.0227

l=3.57682

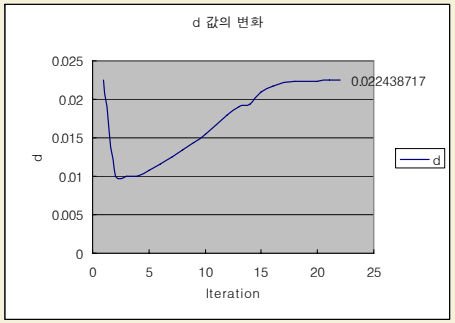
D=0.0227

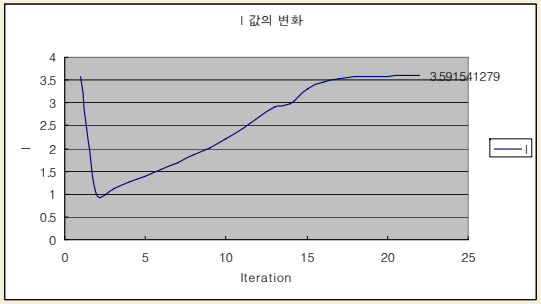
L=0.01116

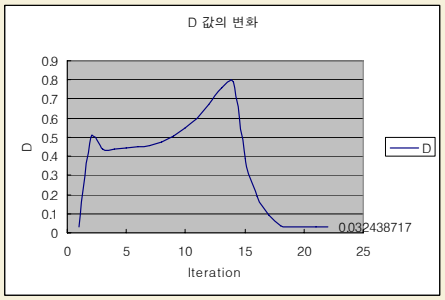
f=12762

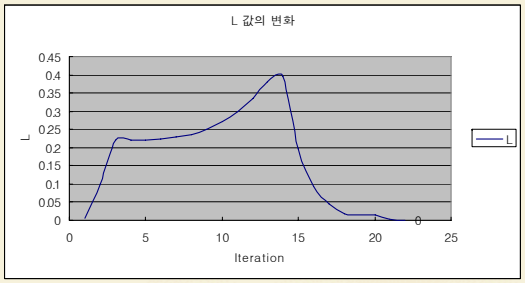
Optimization with GRG

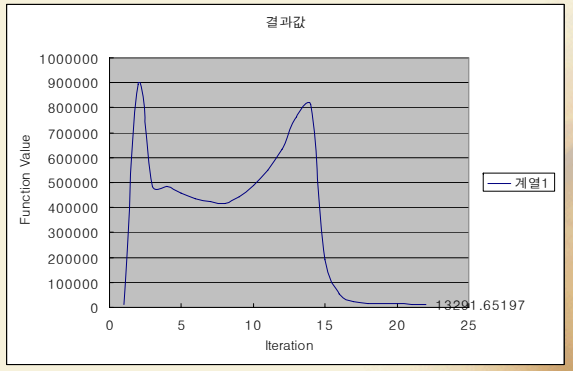
	A	B	C
1	V	8.5	m/s
2	μ	0.00001708	kg/ms
3	ρ	1	kg/m^3
4	K(마찰계수)	0.0187	
5	e	0.00015	m
6	W	49980	원/m^2
7	P o	225.4	N/m^2
8	Q o	0.06666667	m^3/sec
9	g	9.8	m/s^2
10	H(ceiling)	4.355	m
11	H(plate)	0.75	m
12	V c	0.5	m/s
13			
14			
15		초기 값	최적값
16	d	0.01	0.0224312
17	l	1	3.5899858
18	D	0.5	0.0324312
19	L	0.1	0.0052849
20	theta	2.36654504	1.5154179
21	theta	135.593043	86.827049
22	f	894031.791	13256.324
23	g1	2376.21938	-0.045925
24	g2	-47.0584533	1.698E-09
25	g3	-44.4068571	-93.17285
26	g4	-0.48	0
27	g5	-0.9	-3.594701
28	g6	-2.505	-0.009729
29	g7	4.26	-0.45
30	g8	-4.71	4.603E-11
31	g9	-0.3	-0.021861
32	g10	-135.592043	-86.82605
33	g11	-43.4069571	-92.17295











초기 비용	41489	원
최적 비용	13256.324	원
28232.676		원

Summary

- 기존 덕트의 사양
  - d=0.1000, l=2.5700, D=0.1400, L=0.1350, f=41489
- 최적화된 덕트의 사양
  - d=0.0223, l=3.5609, D=0.0550, L=0.0275, f=12523

- 후기
  - 설비공학적 문제의 정식화
  - 초기해에 따른 결과값
  - 알고리즘에 따른 결과값