Chapter 6

DESIGN OF EQUIPMENTS.

Design of Reactor :

Process Design:

The polymerization of styrene is an exothermic reaction. The amount of energy released at any time is dependent on the volume of the reactor, and the rate of removal of that heat is dependent on the surface area. Unless the heat is removed, the temperature will rise and the reaction rate will increase. The result will be an uncontrolled reaction that not only may ruin the batch but could also damage the reactor and might cause fire or explosion to occur.

Therefore there is a maximum size reactor for each set of reaction condition. This size will be calculated. The maximum rate of heat production will be first calculated.

The heat of polymerization = 300 Btu/Pb (from literature)
=300*1.055/0.4536
= 697.79 kJ/kg.

$$\text{The weight of styrene in the reactor} = \rho * V * \frac{1.032}{3.044} \text{--------------(1)}$$

Where,

ρ = Density of mixture
(1/3rd of the way between density of water and styrene)
= 929.086 kg/m^3

V = volume of reactor

$$= \frac{\pi D^2 L}{4} \text{-----------------------(2)}$$

Where D = diameter of reactor
L = length of reactor.

It will be assumed that the reactor is generally 90% full and the height is twice the diameter.

i.e. L = 2D

Therefore equation (1) becomes,

$$\text{Weight of styrene in the reactor} = \frac{0.9*929.086*0.3390*\pi*2*D^3}{4}$$

$$= 445.26D^3 \text{ kg.}$$

Therefore the energy released by polymerization

= Weight of styrene in reactor*heat of polymerization

$= 445.26D^3 * 697.79$

$= 310.698*10^3D^3$ kJ

All this energy must be removed as it is formed.

The cycle time for GPPS = 5.5 hrs

If the time taken for charge and discharge = 1 hr

And time taken to initiate the reaction = 0.5hr

Then all the energy released must be removed in 5.5-1.5

=4.0hr.

$$\text{Therefore average energy produced per hour} = \frac{310.698*10^3D^3}{4}$$

$$= 77.674*10^3D^3 \text{ kJ/hr.}$$

However, the reaction rate is not uniform. The maximum reaction rate must be known to calculate the area needed for heat exchange. It will be assumed that maximum conversion rate is assumed twice the average rate.

i.e. The maximum heat produced per hour = 2* average energy produced/hr.

$$= 2*77.674*10^3*D^3 \text{ kJ/hr}$$

$$= \frac{155*10^6D^3}{3600} \text{ J/s}$$

$$= 42152.778D^3 \text{ J/s.} \quad \text{------------(3)}$$

From literature, for cycle time of 5hrs, the overall heat transfer co-efficient between reaction mixture and the cooling water in jacket is equal to 50 Btu/hr.ft^2.K.= 283.9w/m^{2}K

The rate of heat removed,

$$Q = U.A.\Delta T_o \quad \text{------------------------(4)}$$

Where,

U = overall heat transfer coefficient.

A = area of heat transfer.

ΔT_o= average temperature driving force between coolant and suspension.

Since 95% of the time, the air temperature is below 30°C. It will be assumed that inlet cooling water temperature never exceeds 30°C.

The reaction temperature = 93°C.

It is assumed the maximum cooling water temperature rise is 5°C. Therefore outlet temperature of cooling water =35 °C.

Therefore the average temperature of cooling water =(30+35)/2 = 32.5°C.

Therefore,

$$\Delta T_o = 93-32.5 = 60.5^{o}C.$$

The area of heat transfer is the area covered by the suspension. This can be estimated to be the bottom plus 90% of the sides. (because the reactor is 90% filled).

$$A = 0.9\pi DL + \frac{\pi D^2}{4}$$

$$= 6.44D^2$$

Substituting values of A, ΔT_o and U in equation (4), we get,

$$Q = 283.9*6.44D^2*60.5 \quad \text{----------------------}(5)$$

Comparing equation (3) and equation (5), we get,

$$43152.778D^3 = 283.9*6.44D^2*60.5$$

Therefore,

$$D = \frac{283.9*6.44*60.5}{43152.778}$$

$$= 2.563m.$$

Also,

$$L = 2D$$

$$= 2*2.563 = 5.127m.$$

And,

$$V = \frac{\pi D^2 L}{4}$$

$$= 26.45m^3$$

$$= 6987.35 \text{ gal.}$$

In ‘encyclopedia of polymer technology and science’, the following statement appears:

” In a suspension polymerization of styrene in a 5000 gal reactor, the lowest coolant temperature required is 120°F (49° C)”.

Hence now the average coolant temperature is taken as 49°C instead of 32.5°C.

Therefore,

Outlet temperature of cooling water = 68°C.

And,

$$\text{Average temperature} = \frac{68 + 30}{2} = 49°\text{C}.$$

$$\Delta T_o = 93 - 49 = 44°\text{C}.$$

Also a ‘U’ of 60 BTU/ hr.ft^2.°F or a maximum reaction rate of 1.8 times the average would be better estimates.

Taking maximum heat released per hour = 1.8 times average value.

$$= \frac{1.8*77.674D^3*10^6}{3600}$$

$$= 38837D^3 \text{ J/s}$$

Then,

$$38837D^3 = 60*5.687*6.44D^2*44$$

$$\Rightarrow D = \frac{340*6.44*44}{38837} = 2.486\text{m}.$$

$$L = 2*2.486 = 4.97\text{m}$$

And ,

$$V = 24.124\text{m}^3$$

The amount of styrene produced per reactor per hour is:

$$= \frac{0.9*24.124*929.086*1.032}{5.5*3.044}$$

$$= 1243.43 \text{ kg/hr}.$$

Number of GPPS reactors required is:

$$= \frac{10416.67*1.032*0.6}{1243.43}$$

$$= 5.187 \text{ rectors.}$$

All the above calculations have been done using GPPS. It will be assumed that the same conditions apply to MIPS and HIPS except that the reaction times are different. For economic purpose, the same size reactor will be used for each product. For MPPS the reaction takes 0.5hrs longer; however only1/3rd as much product is planned.

No of MIPS reactors required = $\frac{5.187*0.2*6}{0.6*5.5}$ = 1.886 reactors.

No of HIPS reactors required = $\frac{5.187*0.2*6.5}{0.6*5.5}$ = 2.04 reactors.

Therefore together we need 4 reactors for MIPS and HIPS making a total of 9 reactors needed. An 10th reactor will be installed as a spare. This will allow full production to continue if cleaning out the reactors becomes more of a problem than expected.

Mechanical design:

Data from literature:
Design pressure for the reactor = 220psi = 16.47 kg/cm^2.
Design pressure for jacket = 75psi = 6.27 kg/cm^2.
Permissible stress of reactor = 950kg/cm^2.
Shell internal diameter = 2.486m.
Agitator horse power for 5000gal = 50hp
Diameter of agitator = 1035mm.
Speed = 200rpm.
Agitator blades (flat) = 6
Width of blade =75mm.
Thickness of blades =8mm.
Shaft material – commercial cold rolled steel.
Permissible shear stress in shaft = 550kg/cm^2.
Elastic limit in tension = 2460kg/cm^2.
Modulus of elasticity =19.5*10^{5}kg/cm^2.

Permissible stresses for key (carbon steel)

Shear = $650 kg/cm^2$.

Crushing = $1300 kg/cm^2$.

Stuffing box (carbon steel)

Permissible stress = $950 kg/cm^2$.

Studs and bolts (hot rolled carbon steel)

Permissible stress = $587 kg/cm^2$.

Joint efficiency = 0.85.

Poisons ratio = 0.3.

1.<u>Shell thickness:</u>

(a) Internal pressure:

$$t = \frac{p_i * D_i}{2f_t * J - p_i} + C$$

Where, p_i =16.47kg/cm^2.

D_i = diameter of reactor = 2486mm.

f_t = permissible stress = 950kg/cm$^{2.}$

J = joint efficiency = 0.85.

C = corrosion allowance =3mm.

Therefore,

$$t = \frac{16.47*2486}{(2*950*0.85)-16.47} + 3$$

=28.0mm.

(b) External pressure:

Let t =22mm.

$$L / D_o = \frac{3506.9}{(2486 + 44)} = 1.3758$$

$$D_o/t = (2486 + 44)/22 = 115.8$$

From IS2825, B = 11200.

$$P_a = \frac{11200}{14.22*(2486+44)/22} = 6.85 kg/cm^2. > 6.27 kg/cm^2.$$

Therefore thickness of shell = 24.0mm.

2.<u>Jacket thickness</u>:

Jacket diameter = 1.04 – 1.05 times shell outer diameter.

= 1.045 * (2486+48) = 2623mm.

Therefore,

$$t = \frac{p_i * d_i}{2f_t * J - p_i} + C$$

$$= \frac{6.27 * 2623}{2*950*.85 - 6.27} + 2$$

$$=11.7\text{mm}$$

Take 12mm as thickness of jacket.

3. Stiffening ring:

Required moment of inertia of stiffening ring is as per equation:

$$I = \frac{p_c D_o^3 L}{24E}$$

$$p_c = 4p_e = 4*6.27 = 25.08\text{kg/cm}^2.$$

$$I = \frac{25.08 * (2486)^2\ 4.97}{24 * 1900*10^3} = 4.619*10^4\ \text{mm}^4.$$

Value of I is reduced by 30% to take into account the resistance of the steel.

$$I = 4.916*10^4 - 0.3*4.916*10^4 = 3.441*10^4\text{mm}^4.$$

Use equal angle IS 2020 (size 20*20mm thickness = 3mm).

$I_{xx}=I_{yy} = 0.4\text{cm}^4$.

4. Head thickness:

(a) Internal pressure:

$$t_b = \frac{pR_cW}{2fJ}$$

$$W = \frac{1}{4} * (3 + (R_c/R_l)^{0.5})$$

$$= \frac{1}{4} * (3 + (2486/128)^{0.5})$$

$$= 1.85$$

Therefore,

$$t_b = \frac{16.47 * 2486 *1.85}{2*950*0.85} = 46.90\text{mm}.$$

Use 48mm thickness including corrosion allowance.

(b) External pressure:

$$t_b = 4.4*2486*(3(1-0.3^2)^{0.25}*(6.27/(2*1900*10^3))^{0.5}) = 43.179\text{mm}.$$

Therefore head thickness = 48mm.

5. **Shaft design**:

From equation 14.8(M.V. Joshi)

$$T_c = \frac{50 * 75 * 60}{2*\pi*200}$$

$$= 179.049\text{kgm.}$$

$$T_m = 1.5 * 179.049 = 269.57 \text{ kgm.}$$

From equation 14.9 (M.V. Joshi)

$$Z_p = \frac{1.5T_c}{f_s}$$

$$= \frac{269.57*100}{550} = 49.013 \text{ cm}^3.$$

$$\frac{\pi d^3}{16} = 49.013.$$

⇨ $d = 6.296\text{cm.}$

From equation 14.11(M.V.Joshi)

$$F_m = \frac{1.5T_c}{0.75*25} = \frac{269.57*100}{0.75*25} = 1437.7\text{kgm.}$$

$$M = F_m * l = 1437.3 *1.3 = 1869\text{kgm.}$$

From equation 14.10(M.V.Joshi)

$$M_l = \frac{1}{2}*(1869 + (1869^2 + 269.57^2)^{0.5})$$

$$= 1878.7\text{kgm}$$

From equation 14.3: (M.V.Joshi)

$$f = \frac{1878.7*100}{(\pi*\frac{6.296^3)}{32}} = 7667.67\text{kg/cm}^2.$$

Stress f is greater than permissible elastic limit(2460 kg/cm^2). Therefore use 10 cm diameter shaft for which stress will be,

$$f = 1913.63\text{kg/cm}^2.$$

6. Blade design:

From equation 14.6 and 14.7,

$$f = \frac{\text{maximum bending moment}}{(b_t*b_w^2/6)}$$

$$= \frac{269.57}{(0.8*7.5^2/6)} = 346.09\text{kg/cm}^2.$$

Which is well within the endurance limit for carbon steel.

7. Hub and key design:

Hub diameter of agitator = 2*shaft diameter.
=2*10 =20cm.

Length of hub = 2.5*shaft diameter.
= 2.5*10 = 25cm.

Length of key = 1.5*shaft diameter.
= 1.5*10 = 15cm.

From equation 5.6(M.V.Joshi),

$$\frac{T_{max}}{(d/2)} = l*t*f_s = \frac{l*t*f_c}{2}$$

$$\frac{269.57*100}{(20/2)} = 15*b*650 = \frac{15*t*1300}{2}$$

⇨ b = 5.53mm and t = 5.53mm.

use 6mm*6mm*15cm key.

8. Nozzle for shell:

$$\text{Volumetric flow rate} = \frac{24.124}{30*60} = 0.0134\text{m}^3/\text{s}.$$

Because filling time = 30 minutes.

Q = V*A Take V = 2m/s.

$$A = \frac{\pi D^2}{4}$$

Therefore,

$$0.0134 = \frac{\pi D^2}{4}*2$$

$$\Rightarrow D = \sqrt{0.0134*4/2\pi}$$

= 0.0924m
= 92.4mm
From IS 803,

Nozzle for shell = 100mm

Thickness = 10mm.

Distance from shell to flange = 200mm

9.Nozzle for jacket:

$m = A*V*\rho$ where $m = 2.085$ kg/s.
$V = 1$m/s.
$\rho = 1000$kg/m^3.

$A = 2.085*10^{-3}$m^2.

⇨ D = 51.5mm.

From IS 803,
Nozzle diameter = 75mm.
Thickness = 7.5mm.
Distance from shell to flange = 175mm.

10.Stuffing box and gland:

Internal design pressure = 16.47kg/cm^2.

From equations 5.36(M.V.Joshi),

$$b = d + \sqrt{d}$$

Where d = shaft diameter.

$$b = 10 + \sqrt{10}$$
$$= 13.16 \text{ cm.}$$

$$t = \frac{P_b*b}{2f} + c$$
$$= \frac{16.47*13.16*10}{2*950} + 3$$
$$= 4.14\text{mm.}$$

$$a = b + 2t$$
$$= 13.16 + 2*4.14$$
$$= 13.988\text{cm.} \approx 14.\text{cm.}$$

Load on gland:

$$F = \frac{\pi}{4} * 16.47*(13.16^2 - 10^2) = 946.69\text{kg.}$$

Size of stud:

$$946.69 = \frac{\pi}{4} d_o^2 * n * f_t$$

n= number of baffles = 4

f_t = 587kg/cm^2

$$\Rightarrow d_o^2 = \frac{946.69*4}{\pi*4*587} = 0.5137$$

$$\Rightarrow d_o = 7.16\text{mm.}$$

Minimum stud diameter =15mm.

Flange thickness = 1.75*15 = 26.25mm ≈ 30mm.

11. Coupling:

A clamp coupling is suggested. It is made of cast iron.

$$\text{Force per bolt} = \frac{2*T_{max}}{\mu\pi d + n/2}$$

$$= \frac{2*269.57*100}{\pi*0.25*10*4}$$

$$= 1716.14\text{kg.}$$

$$\text{Area of bolt} = \frac{1716.14}{587}$$

$$= 2.824\text{cm}^2.$$

Diameter of bolt = $(2.924*4/\pi)^{0.5}$ = 1.929 cm = 19.29mm.

Use 20M size bolts.

Overall diameter of coupling = 2*10 = 20cm.

Design of rotary dryer:

Process design:

An air drier removes the excess water remaining in the polystyrene. A rotary drier will be specified. Care must be taken that polymer does not exceed 85°C, or its heat distortion properties will be affected. Therefore this will be chosen as the exit temperature of the air and the airflow will be parallel with the polymer flow. The air will enter at 150°C. It will be assumed that the solids will enter at room temperature i.e. 30°C and leave at 80°C.

To estimate the size the following equations will be used,

$$V = \frac{Q_t}{(Ua_* \Delta T_m)} \quad \text{------(1)} \qquad U_a = \frac{20G^{0.16}}{D} \quad \text{----------(2)}$$

Where,

Q_t = Total energy transferred, kJ/hr.
U_a = Volumetric heat transfer coefficient, kJ/hr.m^2. °C.
ΔT_m = Log mean temperature difference between hot gases and material, °C.
G = Air mass velocity, lb/hr (ft^2 of dryer cross section).
D = Dryer diameter, ft.
V = Volume of dryer, m^3.

Temperatures:	Inlet	Outlet
Polystyrene	30°C.	80°C.
Air	150°C.	85°C.

Heat required raising product to discharge temperature,
= 10612.1496*1.3398*(80-30) + 3.125*4.187*(80-30).
= $7.1156*10^5$W.

Heat required removing water,
= 533.335*4.187*(80-30) + 550 + 0.45*(85-80).
= $1.12205*10^5$W.

Therefore total heat required,
= $7.1156*10^5 + 1.12205*10^5$W.
= $8.23765*10^5$W.

$$\Delta T_m = \frac{(150-30)-(85-80)}{\text{Ln } (150-30)/(85-80)} = 36.186°\text{C}.$$

The minimum air velocity is set by the particle size. A flow rate of 1000lb/hr.ft^2 is adequate for 420-micron particle. This will be used. The minimum velocity is used since it gives the smaller dryer.

The amount of air required is determined by amount of energy the 150°C. air must supply to remove the moisture from the polystyrene.

$$m = Q_t /(C_p.\Delta T).$$

Where,

C_p = heat capacity of air = 0.237 BTU/lb.°C.
ΔT = difference in air temperature entering and leaving dryer,°C.
Q_t = heat transferred in dryer =8.23765*10^{5}W.
m = mass flow rate of air.

$$m = \frac{8.23765*10^5}{(0.9923*(150-85))} = 12771.65\text{kg/hr.}$$

Maximum amount of water that can be in air = 12771.65(kg/hr)* 0.7(kg water/kg dry air)

= 8940.155 kg water/hr.

Amount of water to be removed = 10416.67 * 0.0497
= 518 kg water/hr.

The amount of air is adequate. Add 10% to account for possible heat losses.

Therefore mass flow rate = 1.1* 12771.65
= 14048.87 kg/hr.

If the mass velocity = 1000lb/hr.ft^2
= 4880 kg/hr.m^2.

Then,

$$\text{Area of dryer} = \frac{14048.82}{4880} = 2.876\text{m}^2.$$

Therefore,

$$\text{Diameter of dryer} = \sqrt{(2.876*4/\pi)}$$

$$= 1.914\text{m.}$$

From equation (2),

$$U_a = \frac{20*(1000)^{0.16}}{(6.279)}$$

$$= 9.619\text{BTU/(hr.ft}^3\text{.°F).}$$

$$V = \frac{7.80778*10^5}{9.619*97.1348}$$

$$= 835.699\text{ft}^3$$

$$= 35.2198\text{m}^3$$

Therefore,

$$L = \frac{V*4}{\pi D^2}$$

$$= \frac{35.2198*4}{\pi*(1.914^2)}$$

$$= 12.24\text{m.}$$

Mechanical design:

1. **Flight design:**

   Number of flights = 3*D.

   = 3*6.28

   =18.83 ≈ 19 flights are required using lip angle of 45°.

   Radial height is taken as 1/8 of diameter,

   Radial height = 1.914/8 = 0.2393m.

2. **Thickness of dryer:**

   Let x be the thickness of drier.

Mild steel can be used since it can withstand temperature up to 200°C.
Density = $7688.86 kg/m^3$.

$D_2 - D_1 = 2x$.
Volume of mild steel $=(\pi D_2^2/4 - \pi D_1^2/4)*L$

$$=(\pi(D_1+2x)^2/4 - \pi D_1^2/4)*L$$

$$= \pi DLx.$$

Weight of dryer = $\pi*12.24*1.914*x*7688.86$
$= 565.89*10^3x$ kg.

Assume holdup = 0.2
Volume of drier filled with material $= \frac{\pi}{4} D^2L*0.2$

$$= \frac{\pi}{4}*1.914^2*12.24*0.2$$

$$= 7.04 m^3.$$

Weight of material at any time = 7.04 * 1049.2
= 7389.98kg.

The dryer is supported over two-trunsion roll assemblies, 20ft apart. It is uniformly distributed load.

Maximum bending moment = WL/8 = M.

$M = (565.89x/8 + 7389.98/9)*12.24$
$= 865.81*10^3x + 11306.7$

We know that,

$M = f*Z$. -------------(1a).

$Z = \pi*(D_2^4 - D_1^4) / 32D_2$.
$= 0.785x^3 + 12.59x^2 + 67.31x$.

f = 1800psi.

Take factor of safety = 5.

$f = 3.6*10^5 lb/ft^3$.
$= 1.75767*10^4 kg/m^2$.

Equation 1a becomes,

$865.81*10^3x^3 + 11306 = 1.75767*10^4*(0.785x^3 + 12.59x^2 + 67.31x)$
$\Rightarrow x^3 + 16.04x^2 + 22.99x - 0.819 = 0$

x(m)	RHS
0.5	14.712
0.25	5.84
0.125	2.208
0.1	1.542
0.01	1.02
0.04	0.027
0.02	-0.45

But minimum thickness =6mm. Therefore thickness of dryer is 6mm.

3. Thickness of insulation:

Insulation material = asbestos.

Density of asbestos = 36lb/ft^3.

Thermal conductivity of asbestos = 0.12BTU/hr.ft^2.^{o}F.

= 0.2077w/mK.

Material of dryer = mild steel.

Thermal conductivity = k = 26BTU/hr.ft^2.^{o}F.

Convective heat transfer coefficient from dryer surface = 56.78W/m^{2}K.

Heat loss from the dryer = 3.31*10^5 BTU/hr = 3.492*10^{5}kJ.

D_1 = 1.914m t = 6mm D_2= 2.034m L = 12.24m

Let X be the thickness of insulation .

$$Q = (T_1 – T_2) / (t_1/ kA_1+ t_2 /kA_2+ 1/A_cA_3) \text{ -------(A)}$$

$A_1 = (D_1 + D_2)L\pi/2$

= 75.83m^2

$A_2 = \pi(D_2 + D_3)L/2$

= 78.2 + 38.45X

$A_3 = \pi D_3L$

= 78.2 + 76.9X

$T_1 = 150°C$

$T_2 = 85°C$

Substituting in Equation A, we get,

$3.492x10^5 = (150 – 85)/ (0.01/(44.99*75.83) + X/(78.2 + 38.45X) + (1/(78.2+76.9X)$

⇨ X = 6mm.

4. BHP to drive the drier:

$$BHP = \frac{Nx(4.75dw + 0.1925DW + 0.33W)}{100000} \text{-------------(B)}$$

where,

N = revolutions per minute = 3rpm.

d = 1.914m = 6.27ft.

D = d + 2 =6.27 + 2 = 8.27ft.

w = 11148.6 kg = 24578lb.

W = weight of drier+ weight of material + weight of insulation.

$$= \pi*12.24*1.914*0.01*7688.86 + 11148.6 + \frac{\pi}{4} ((2.622^2 – 2.61^2)*12.24*576.665)$$

= 18199.7kg

= 40123.47lb.

$$BHP = \frac{3x(4.75*6.27* 24578 + 0.1925*8.27*40123 + 0.33*40123)}{100000}$$

= 24.273BHP.

5. To find diameter of feed pipe:

Feed rate = 10612.14 +536.46 = 11148.6096kg/hr.

Density of feed =1012kg/m^3.

$$\text{Volumetric feed rate} = \frac{11148.6096}{1012} = 11.06m^3/hr.$$

Assuming a velocity of 150m/hr for feed chute inclination of 60°.

Cross section area of feed chute = 11.06/150 =0.0736m^2.

Therefore diameter of feed chute = $(0.0736*4/\pi)^{0.5}$
= 0.306m.

6. **Horse power of blower:**

Atmospheric air = 30°C.

Humidity = 0.002kg/kg dry air.

Quantity of air handled = 12771.65kg/hr.
= 212.8kg/min.

Total quantity of air = 1.02*212.8
= 217.12kg/min.

Volume of the air = $\frac{217.12*22.4*303}{29*298}$ = 170.52m^3/min.
= 6021.8ft^3/min.

Air horse power of blower = 0.000157*Q*(developed head of water(in))
=0.000157*6021.8*10
= 9.45hp.

7. **Horse power of exhaust fan:**

Outlet temperature of air from dryer = 85°C.

Humidity of outlet air = 0.00726

∴ Total quantity of air going out = 212.8kg/min.

Volume of this air = $\frac{212.8*22.4*368.62}{29*298}$

= 203.09m^3/min.

= 7172.06ft^3/min.

∴Air horsepower of exhaust fan for developed head of 10” water,

= 0.000157*7172.06*10

= 11.26 HP.

8. To find diameter of inlet and outlet:

At inlet conditions of 150°C and humidity of 0.002,

Volume of air handled = 170.52*423/303
= 238.02m^3/min.
= 3.967m^3/s.

Assume an air velocity = 10m/s.

Cross sectional area of inlet pipe = 3.967/10
= 0.3967m^2.

∴Diameter of pipe = $(0.3967*4/\pi)^{0.5}$
= 0.711m.

At outlet conditions,

Volume of air = 170.5*(273+85)/303
= 201.45m^3/min.
= 3.357m^3/s.

Cross section area of outlet pipe = 0.3357m^2.

∴Diameter of outlet pipe = $(0.3357*4/\pi)^{0.5}$
= 0.6538m.