EQUIPMENT DESIGN

CONDENSATION POLYMERISATION REACTOR DESIGN

Model selection reference of reaction kettle

Composition	Type
Specification (L)	50-50000
Design Pressure (Mpa)	Atmospheric Pressure or under pressure
Material	Titanium Clad steel
Heating Forms	Electrical heating with medium in jacket, external half coil steam heating, external half conduction oil heating, hot water infrared heating
Cooling Forms	Refrigeration medium in the internal pipe jacket
Blending Power	Model selection is made according to material viscosity, liquid-solid ratio, liquid specific gravity, solid specific gravity, solid granularity, rotation speed, paddle type, with or without baffle or internal coil.
Stirring blade Forms	Ribbon Type
Seal	Mechanical seal
Inner Surface Treatment	Polished
Discharge Valve	Open downward discharge valve
Technological Pipe Hole	Manhole, pressure gauge port, temperature, mouth

All parts of the equipment that contact with the material are all made by stainless steel (SS304)

APPARATUS:

(1) Thermocouple: It is a sensor used to measure temperature.

(2) Heating mantle: The heating will be provided by an electrical heating mantle

(3) Pressure Equilibrium.

(6) Dean-Stark apparatus: removal of formed water (Lab Scale)

(7) Thermometer: to measure the vapor temperature

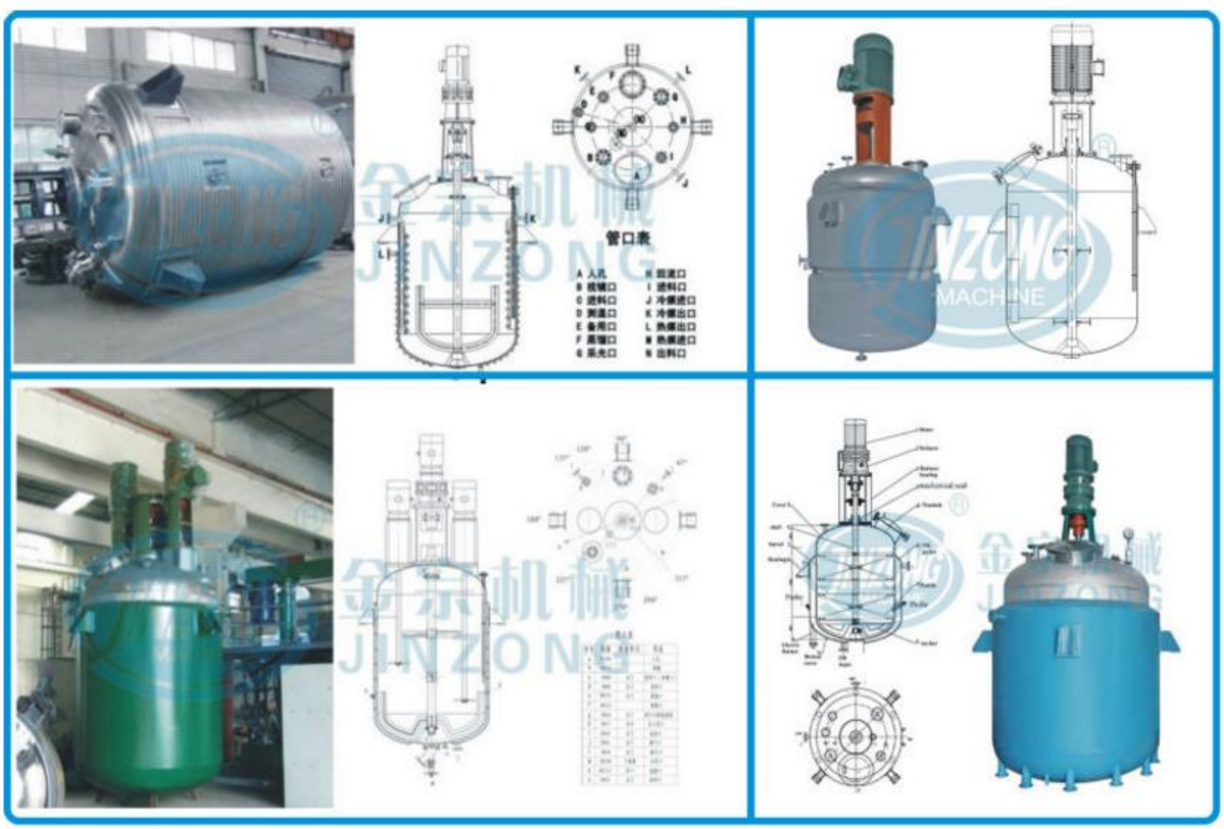
(9)Double Helical Ribbon Type Agitator: Heat and Mass transfer are greatly influenced by agitation. It produces high velocity liquid streams, which moves through the vessel and comes in contact with the slower moving liquid creating momentum transfer. Viscosity of the mixing liquid greatly determines the type of agitator being used. Helical agitators are an effective device in mixing high viscosity fluids.

(11) PID controller.

STRUCTURE:

Batch Reactor has been used. These are exclusively used for liquid phase reactions. The reactants are added to the empty vessel and the contents are removed after completion of the reaction. A thermocouple should be used to control the reaction temperature, which is connected to a PID controller and this one to the electrical heating mantle. At the beginning of the reaction the nitrogen flow does not need to be very high (about 2 bubbles/second), as water come out easily as it is formed in higher quantities in the beginning of the reaction (as predicted from the reaction equilibrium). The stirrer should be started at the same time or 3-4 minutes after heating and should continue throughout the synthesis process. A small pre-heat should be done so that stirrer do not exceeds its maximum power. At first, the set point in PID controller for the temperature of the reaction mixture should be around 180ºC. At 170-180ºC the reflux will start and the temperature of the vapor should be controlled in by using a thermometer. The temperature set in the PID controller is 220ºC. After most of the water has been distilled the reaction becomes very slow. The total time cycle of the polyesterification reaction in this second phase can be reduced in 3 different ways:

- The flow of nitrogen can be increased with careful monitoring of glycol loss;
- The speed of the stirrer can be increased;
- Reduced pressure can be applied with special care to prevent foam rising.



REACTOR FUNCTIONING:

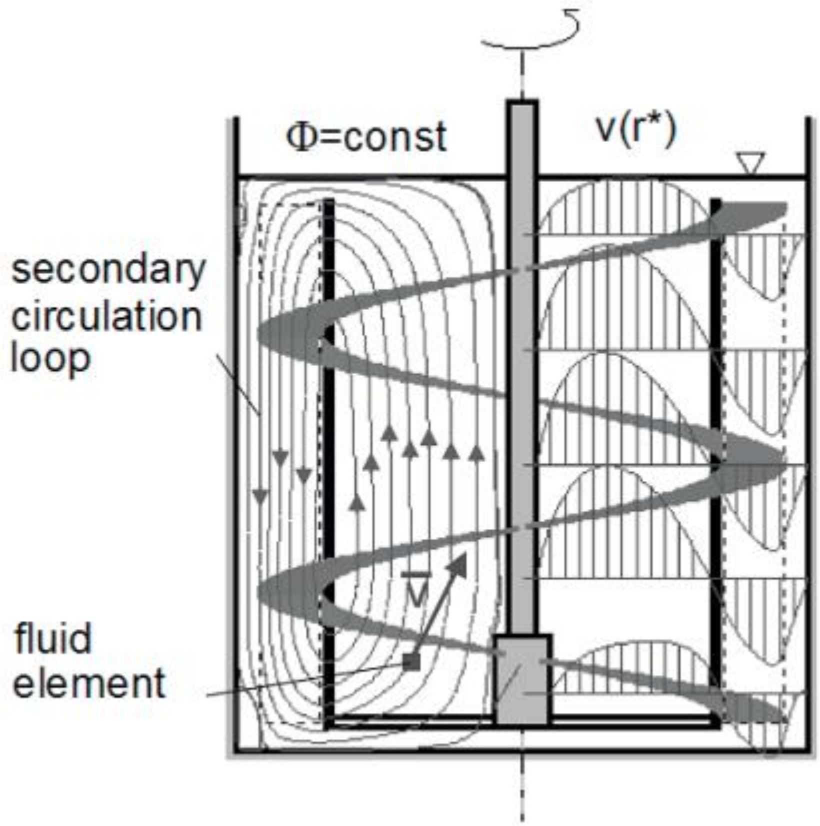


Fig. 1. Secondary circulation in a mixer, where: Φ – lines connecting points of equal dimensionless average axial velocity, r^* – dimensionless radius

MECHANICAL DESIGN OF REACTOR:

Technical parameter

技术参数Technical specifications

代号Code 规格Type	500L	1000L	1500L	2000L	3000L	4000L	5000L	6000L
筒体尺寸 Cylinder Size (mm)	900×800	1100×1200	1300×1200	1400×1500	1600×1500	1700×1800	1800×2000	1900×2000
实际容积 Actual Capacity (L)	699	1400	2166	3000	4066	5400	6600	7700
外管规格 Outer Tube Size (mm)	ϕ76/2	ϕ76/2	ϕ76/2	ϕ76/2	ϕ89/2	ϕ89/2	ϕ89/2	ϕ89/2
加热面积 Heating Area (m^2)	1.7	2.6	3.8	4.5	5.8	7	7.5	8.7
内盘管规格 Inner Coil Size (mm)	ϕ38	ϕ45	ϕ45	ϕ45	ϕ45	ϕ57	ϕ57	ϕ57
冷却面积 Cooling Area (m^2)	1.6	2.7	3.6	4.3	5.7	6.8	8	9
电机功率 Motor Power (kw)	3	4	5.5	5.5	7.5	11	11	15
减速机型号 Reducer Model	XLB4-17-3	XLB4-17-4	XLB4-17-5.5	XLB5-17-5.5	XLB5-17-7.5	XLB6-23-11	XLB6-23-11	XLB7-23-15
机架 Frame	JXLD4-45	JXLD4-45	JXLD5-55	JXLD5-55	JXLD5-55	JXLD6-65	JXLD6-65	JXLD7-80

Volume of the reactor = V = 699 L= 0.699 m^3

Assuming L/D = 1.125

V = ($\Pi D^2/4$) x L = ($\pi/4$) x 1.125*$(D)^3$

⇒ Diameter, $D_i = (4V/1.125\pi)^{1/3} = [4 \times 0.699 / (1.125 \times \pi)]^{1/3}$ = 0.925m

⇒ Height, L = V*4/(π x D^2) = 1.0406m

<u>AGITATOR DESIGN</u>:

The diameter of helical impeller varies from 50 to 90 % of tank diameter.

Assuming that turbine operates at 70 rpm

Diameter of reactor = 0.925 m

Diameter of agitator = 40/100*D_i= 0.4 x 0.925

= 0.37 m

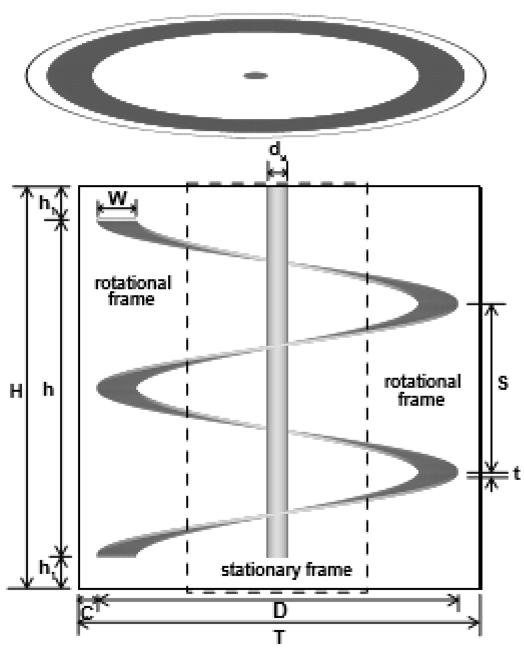
i.e using 40% of diameter of reactor as impeller diameter

W/D_a= 0.25

Width of the blade= 0.25*D_a= 0.0925 m (Optimised Blade: giving optimum performance)

Thickness of Blade= 0.005 m

Clearance= 0.037m (gap between the vessel wall and impeller blade)



VORANOL Diol Polyether Polyols

The diol line of VORANOL polyether polyols are well suited for use in numerous applications, including microcellular reaction injection molding (RIM), prepolymers, sealants, and other polyol blends.

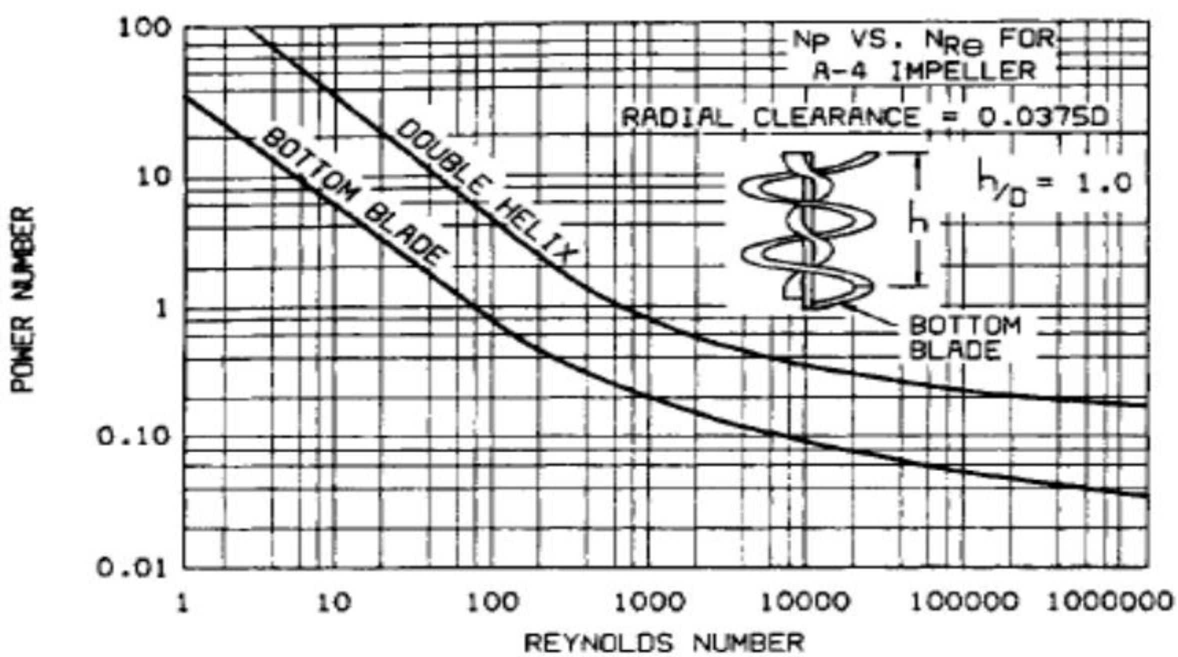
Product	OH Number	Function-ality	Average Mol. Wt.	Initiator	Flash Point[1] °F (°C)	Density lb/gal (g/cc)	Viscosity[2] @ 77°F	Viscosity @ 100°F	Viscosity @ 150°F	Viscosity @ 210°F
VORANOL 220-028	28	2.0	4,000	propylene glycol	446 (230)	8.36 (1.00)	880	465	140	53
VORANOL 220-056N	56	2.0	2,000	propylene glycol	390 (199)	8.34 (1.00)	300	160	60	23
VORANOL 220-094	94	2.0	1,200	propylene glycol	435 (224)	8.43 (1.01)	175	92	31	13
VORANOL 220-110N	110	2.0	1,000	propylene glycol	360 (182)	8.37 (1.00)	160	80	28	11
VORANOL 220-260	260	2.0	432	propylene glycol	330 (165)	8.43 (1.01)	75	33	12	4.7
VORANOL 220-530	530	2.0	212	aniline	325 (163)	8.39 (1.00)	solid	6,000	200	13
VORANOL 222-029	29	2.0	4,000	propylene glycol	420 (216)	8.49 (1.02)	790	410	168	62
VORANOL 222-056	56	2.0	2,000	propylene glycol	>420 (>216)	8.46 (1.01)	321	168	63	25

Density of polyol mixture, ρ =1000 kg/m3

Viscosity of mixture, μ = 53 cP

$N_{Re} = \rho N D a^2/\mu$ = [1000x 70/60 x $(0.37)^2$] / 53= 2.7

From M.V. Joshi, Process Equipment Design,



From power curve, Np = 120 for Reynolds number 2.77

Power, P = Np*ρ* N^3*Da^5= (120 x 1000x $(70/60)^3$x $(0.37)^5$) = 1321.38W

Power losses (10%) = 132.138W (helical gears have efficiency of power transmission 90%)

Power input = 1321.38 + 132.138 = 1453.52W

Transmission system losses (20%) = 1453.52 x 0.2= 290.7W

Total Power= 1453.52 + 290.7= 1744.22W

This will be taken as 1750W to allow for fitting losses. It is advisable to use 1750W motor.

The ribbon angle of the helical agitator will be **83.7 degrees.**

Tab. 1. Parameters of helical-ribbon impellers

Impeller	Diameter of impeller *d* [m]	*d/D* [-]	Height *h* [m]	*h/D* [-]	A number of coils *i* [-]	Pitch of rib-bon *p* [m]	*p/d* [-]	The ribbon angle β [°]
R1	0.28	0.959	0.26	0.890	1	0.260	0.929	72.6
R2	0.28	0.959	0.26	0.890	2	0.130	0.464	80.6
R3	0.28	0.959	0.26	0.890	3	0.087	0.311	83.7
R4	0.27	0.925	0.26	0.890	2	0.130	0.481	80.2
R5	0.26	0.890	0.26	0.890	2	0.130	0.5	79.8

SHAFT DESIGN:

Continuous average rated torque on the agitator shaft, Tc= P/2 π N= 1750/ (2 π 70/60)= 238.85Nm

Polar modulus of the shaft cross section is, Z_p = Tm/fs

Where Tm is maximum torque= 1.5*238.85 = 358.28 N/m

Permissible Shear Stress= fs= 55 N/mm^2

Z_p= 358.28*10^3 /55= 6514.18mm^3

Π*D_s^3/16= 6514.18

D_s = 32.137 mm= 0.032 m

CRITICAL SPEED:

Actual speed is 40% of the critical speed

Critical speed N_c= 70/0.4

= 175 rpm

Since actual shaft speed is 70 rpm which is 40% of the critical speed.

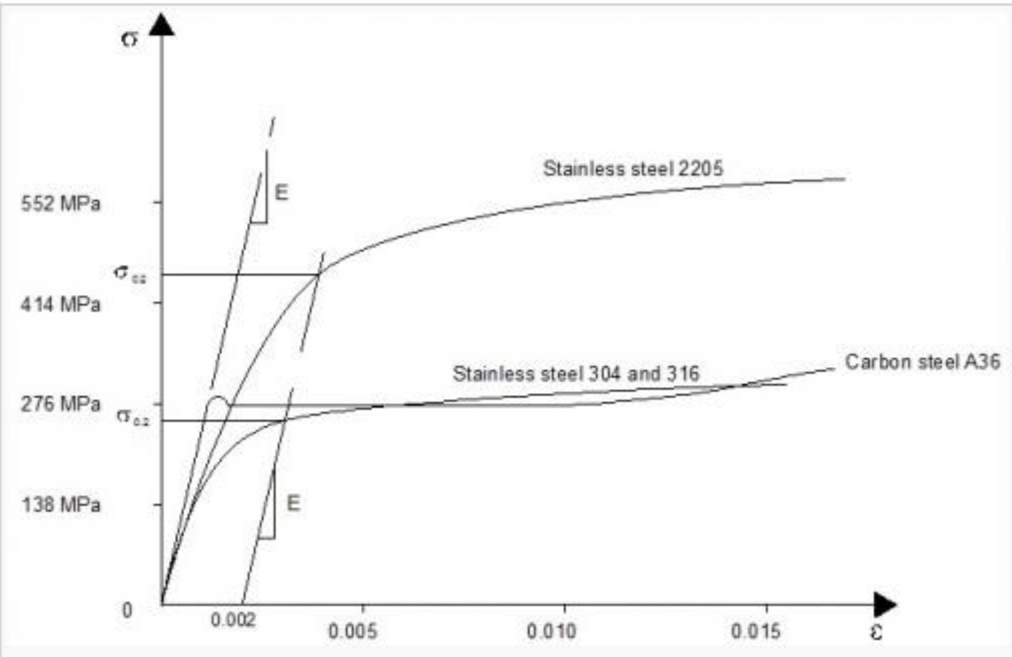
BLADE DESIGN:

No. of blades = 4 (for efficiency, typically 2 are used)

Using blade width, w = 0.0925m

Blade thickness, t = 0.005m

Stress in the blade, F= (maximum torque)/(tw^2/n)= (358.28)/(0.005 x 0.0925^2/4) = 33MPa < 276M



Stress – strain behaviour for steel

The value of stress is well within the limit for carbon steel.

MECHANICAL SEAL:

It consists of two surfaces (rings), one on the rotating shaft and the other is stationary. It has a rotary ring made of steel which is held on the shaft by a flexible O-ring made of Teflon. A stationary ring made of carbon (low coefficient of friction) is placed in a box through another O-ring. O-ring compensates for lack of alignment, thermal expansion and shaft vibration.

THICKNESS OF VESSEL:

MegaStir TECHNOLOGIES

304 Stainless Steel

304 FSW Transverse Tensile Properties			
Sample	**Yield Strength 0.2 % offset KSI (MPa)**	**Ultimate Tensile Strength KSI (MPa)**	**Elongation %**
400 RPM, 3 IPM	*51 (352)*	*95 (655)*	*54*
Base Metal	*55 (379)*	*98 (675)*	*56*

•Tensile failures occurred in HAZ

Allowable stress value, f = 950 kg/cm^2 (upto 6679 kg/cm^2 for Stainless Steel 304)

Thickness of reactor, t = $(PD_i)/[(2fj)-P] + C$

Where

'j' is joint efficiency = 0.85

'P' is the design pressure

P = 1.1*30

= 1.1 x 30

= 33 kg/cm^2

t = (33 x 925)/[(2 x 650 x 0.85)-33] + 3

= 31.47 mm with corrosion allowance

Thickness of reactor vessel = t = 31.47 mm = 0.03 m

DESIGN OF REACTOR HEAD (TORISPHERICAL):

Using Flat head

Thickness of head, t = $(C*D_i/10)$

Where 'C' is taken as 0.5

(IS 2825 – 1969)

t = (0.5 x 925/10)

= 46.25 mm

= 49.25 mm with 3mm allowance for corrosion

DISHED BOTTOM THICKNESS

T_h =PD_i /2 x f x J

T_h = 33 x 925 / (2 x 650 x 0.85) + 3

= 30.62 mm

JACKET DESIGN

Jacket Diameter= 1.045 * 0.955= 0.997975m

Jacket Thickness= (PD_i)/[(2fj)-P] + C = 13*997.9/(2*650*0.85-13) + 2 = 13.8mm = 0.0138m

Hence approximately 0.014m is the jacket thickness

WEIGHT CALCULATIONS:

Length of reactor = 1.0406m

Outside diameter of reactor = 0.955 m

Inner diameter of reactor = 0.925 m

Density of structure steel = 8000 kg/m3 (SS304)

Weight of reactor vessel,

W_1 = 8000 x π/4 (0.955 – 0.925) x 1.0406 = 196.049 kg.

Weight of Adipic acid,

$W_2 = \pi/4\ (Di^2)\ L\ \rho$

$= \pi/4 \times 0.925^2 \times 1.0406 \times 1344$

= 939.36 kg

Weight of the head

$W_3 = t \times L \times b \times \rho$

$= 49.25 \times 10^{-3} \times 1.0406 \times 1.0406 \times 8000$ = 426.64 kg

Weight of the BDO

$W_4 = \pi/4\ (Di^2)\ L\ \rho = \pi/4 \times 0.925^2 \times 1.0406 \times 1017$ = 710.81

Weight of Agitator Assembly

Specification Dimensions

0.4 kW or more for 6-pole motor (customer order). Also, body, shaft diameter and propeller diameter dimensions increase by one more rank.

Model	Motor Output	Revolution Speed (min^{-1})		Agitation Shaft		3-vane propeller		Main Body			Mounting Flange			Hole		Max. Agitation Capacity		Approx. Weight
				Standard length (L)	Dia. (Dia. D)	1st stage dia.	2nd stage dia.	(H)	(A)	(B)	Nominal dia. JIS-10K	O.D. (OD)	Pitch (PCD)	(Z)	(N)	Diluted Liquids	Medium Viscosity Liquid	W/ motor
	kW	50Hz	60Hz	mm	mm	mm	mm	mm	mm	mm		mm	mm	mm	PCS	L	L	kg
BTO - 0.1	0.1			800	13	200	160	269	150	270	100A	210	175	19	4	600	200	24
BTO - 0.2	0.2			1000	16	250	200	269	150	270	100A	210	175	19	4	1200	400	25
BTO - 0.4	0.4	295	350	1200	22	300	250	347	150	360	125A	250	210	23	4	2500	800	37
BTO - 0.75	0.75	(4-pole motor)	(4-pole motor)	1400	22	350	300	347	150	360	125A	250	210	23	4	5000	1500	47
BTO - 1.5	1.5	190	230	1600	32	400	350	428	210	420	150A	280	240	23	4	10000	3000	76
BTO - 2.2	2.2	(6-pole motor)	(6-pole motor)	1800	32	450	400	428	210	420	150A	280	240	23	4	15000	5000	87
BTO - 3.7	3.7			2000	40	480	450	508	210	470	200A	330	290	23	4	20000	8000	143
BTO - 5.5	5.5			2200	50	550	480	658	285	540	250A	400	355	25	6	30000	12000	285

Since we have a motor power output of 1.75 kW which is closest to 1.5 kW.

Matching this with the above standard specifications we get the, W_5=76 kg

Total weight $W = W_1 + W_2 + W_3 + W_4 + W_5$ = 2348.86 kg

Design weight = 1.3 x 2348.86

= 3053.518 kg.