LIST OF ANNEXTURES

ANNEXTURE - A

LIST OF SYMBOLS & GLOSSARY

SYMBOLS

1. A = Cross Sectional Area of Extrudate.
2. b = Shape Function.
3. b^* = Factor Representing Deformation Occuring in Inlet Zone.
4. Bi = Biot Number.
5. c = Characteristic Relaxation time.
6. C_p = Specific Heat Capacity.
7. D,t = Thickness of Extrudate.
8. G = Elastic Shear Modulus.
9. H_1 = Height of slit die at Land.
10. H_2 = Height of Slit Die, Before Taper Section.
11. H_3 = Equivalent Height of Product.
12. H_E = Height of Slit Die Extrudate at equilibrated Swell State.
13. h_i = Slit or Cone, Die Inlet Height.
14. h_o = Slit or Cone, Die outlet Height.
15. K = Proportionality Factor of Power Law Equation, $\tau = K(\gamma)^n$
16. K^* = Constant related to Short Die Swell Model.
17. L = Length of a Flow Channel.
18. m = Power Law Index of Power Law Equation, $\gamma = \phi.(\tau)^m$
19. N = Power Law Index of Power Law Equation, $\tau = K(\gamma)^n$
20. p = Rheological Parameter Related to Stevenson Die Design Model.
21. q = Rheological Parameter Related to Stevenson Die Design Model.
22. Q = Volumetric Flow Rate. (m^3/s)
23. R = Radius of a Flow Channel.
24. r = Rheological Parameter Related to Stevenson Die Design Model.

25. s = Rheological Parameter Related to Stevenson Die Design Model.

26. S, B = Die Swell.

27. $T_{(x,t)}$ = Temperature of The Extrudate at x Distance and at Time t.

28. T_F = Cooling Media Temperature.

29. T_M = Melt Temperature.

30. t_v = Residence Time.

31. V = Volumetric Flow Rate. (mm^3/s)

32. W_1 = Width of Slit Die at Land.

33. W_2 = Width of Slit Die, Before Taper Section.

34. W_3 = Equivalent Width of Product.

35. W_E = Width of Slit Die Extrudate at equilibrated Swell State.

36. z = Distance Along z Axis.

37. ΔP = Pressure Drop.

38. Φ = Degree of Cooling.

39. Θ = Horizontal Convergent Angle of Two Dimensional Converging Flow Channel.

40. α = Size Factor.

41. α_h = Heat Transfer Coefficient in Calibration Equipment.

42. α_t = Linear Coefficient of Thermal Expansion.

43. α_0 = Half Natural Convergent angle in Extrusion Dies.

44. β = Shape Function.

45. δ = Heat transfer Related Variable.

46. ε = Tensile Strain.

47. $\varepsilon^{\cdot}$ = Tensile Deformation Rate.

48. ϕ = Proportionality Constant of Power Law Equation, $\gamma = \phi.(\tau)^m$

49. γ = Shear Rate.

50. η = Absolute Viscosity.

51. λ = Thermal Conductivity.

52. μ = Friction Coefficient.

ANNEXTURE - B

LIST OF EQUATIONS

(1). $Q = \Pi.\Delta P.R^4/(8\eta.L)$

Q = Melt flow rate in a capillary.

Π= A constant.

ΔP= Pressure drop across the capillary.

R = Radius of the capillary.

L = Length of the capillary.

η = Viscosity of the fluid.

(2). $\tau = \eta.\gamma$

τ = Shear stress

η = Viscosity of the fluid.

γ = Shear rate.

(3). $\sigma = E.\,\varepsilon$

σ = Tensile Stress

ε = Tensile Rate

E = Tensile Modulus.

(4). $\tau = \eta.\gamma^n$

τ = Shear stress

η = Viscosity of the fluid.

γ = Shear rate.

n = Power Law index

(5). $\Delta P_{ToT} = \Delta P_{ent} + \Delta P_{tube} + \Delta P_{exit}$

ΔP_{ToT} = Total Pressure Drop

ΔP_{ent} = Entrance Pressure Drop.

ΔP_{tube} = Pressure Drop Due to Flow Resistance.

ΔP_{exit} = Pressure Drop at the Die Exit.

(6). $Q = [n. \Pi R^3/(3n+1)]^*\{R.\Delta P/2KL\}^{1/n}$

ΔP = Pressure Drop in the Tube.

R = Inside Radius of the Tube.

L = Length of the Tube.

K = Power Law Constant.

n = Power Law Constant.

(7). $\Delta P/L = [\, 2^{m+1}.(m+2).V/(\phi.B.H^{m+2})]^{1/m}$

ΔP = Pressure Drop Across the Rectangular Slit.

L = Length of the Slit.

M = Power Law Index of the Melt.

ϕ = Proportionality Constant in the Power Law.

V = Volumetric Out Put Across the Slit.

B = Breadth of the Rectangular Slit.

H = Height of the Rectangular Slit.

(8). $\varepsilon_{cone} = \frac{1}{2}\gamma \tan\omega$

ε = Extensional strain rate

γ = Shear rate at the exit of the taper

ω = Half angle of taper

(9). $\varepsilon_{slit} = 1/3.\ \gamma\tan\omega = \gamma.(h_i - h_0)/6L$

ε = Extensional strain rate

γ = Shear rate at the exit of the taper

ω = Half angle of taper

(10). $\Delta P_{ToT} = \Delta P_{ent} + \Delta P_{land} + \Delta P_{shear} + \Delta P_{exit}$

ΔP_{ToT} = Total Pressure Drop.

ΔP_{ent} = Entrance Pressure Drop.

ΔP_{land} = Land Pressure drop.

ΔP_{shear}= Pressure Drop due to Shear.

ΔP_{exit} = Pressure Drop At Exit Of The Die

(11). $\Delta P_S = \iota/2n\tan\omega\{1-(h_0/h_l)^{2n}\}$

ΔP_S = Pressure drop due to shear flow.

τ = Shear Stress

n = Flow behavior index

ω = Half angle of taper

h_0 = Thickness of wedge at Outlet

h_1 = Thickness of wedge at Inlet

(12). $\Delta P_{EXT} = 1/2\sigma_0\{1 - (h_0/h_l)^{2n}\}$

ΔP_{ENT} = Pressure drop due to shear flow.

σ_0 = Tensile Stress Corresponding to Tensile Deformation Rate.

n = Flow behavior index

h_0 = Thickness of wedge at Outlet

h_1 = Thickness of wedge at Inlet

(13). $\Delta P = [\eta.\cot\theta(Q(4n+2/W_1n))^n][(H_2^{-2n}-H_1^{-2n})/2n*(1+nH_1\cot\theta/W_1\cot\Theta) +(H_2^{1-2n}-H_1^{1-2n})*(n\cot\theta/W_1(1-2n)\cot\Theta)]$

ΔP = Pressure drop across the wedge.

θ = Vertical taper angle of the wedge.

Θ = Lateral taper angle of the wedge.

n = Power law index.

H_1 = Height of wedge at taller end of the wedge.

H_2= Height of the wedge at the shorter end of the wedge.

W_1= Width of the wedge at the shorter end of the wedge.

(14). n = 1/m

n,m = Power law indexes used in different equations.

(15). $K = (1/\phi)^{1/m}$

K = Proportionality constant in power law equation.

ϕ = Proportionality constant in power law equation

m = Power law index.

(16). $B_R^2 = 2/3^* \gamma_R[(1+1/\gamma_R)^{2/3} - 1/\gamma_R^3]$

B_R = Swelling Ratio

γ_R = Recoverable Shear Strain.

(17). $G = \tau/\gamma_R$

G = Elastic Shear Modulus

τ = Shear Stress

γ_R = Recoverable Elastic Shear Strain.

(18). $S = a + b^*.e^{(-tv/c)}$

S = Swelling Potential

a = Velocity Profile

t_v/c= Characteristic Relaxation Time of the Melt

b* = Representing Factor for Deformation Occurring at the Inlet.

(19). $B = [1 + 3/2.(n+1).K.\tan^2\alpha_0.(\Delta P_{ENT}/\tau_w)]^{1/2}$

B = Die swell value.

n = Power law index.

$K = L_e/D_c$

α_0 = Half natural convergent angle of polymer melts.

ΔP_{ENT} = Entry pressure drop.

τ_w = Shear stress at the die wall.

L_c = Length of the entry converging region.

D_c = Diameter defined in the diagram.

(20). $\alpha_{ij} = A_i/A_j$

α_{ij} = Size factor between points I and j

A_i = Extrudate cross section at position i.

A_j = Extrudate cross section at position j.

(21). $\beta_I = X_i/(A_I)^{1/2}$

β_I = Shape factor at point i.

X_I = Characteristic dimension of extrudate at position i.

A_I = Area of extrudate at position i.

(22). $\beta_{ij} = b_i/b_j = (X_j/X_I)/(A_j/A_I)^{1/2} = X_j/X_i/(\alpha_{ij})^{1/2}$

β_{ij} = Shape factor between points I and j.

X_j = Characteristic dimension at position i.

X_I = Characteristic dimension at position j.

α_{ij} = Size factor between points I and j.

(23). $\beta^y_{ij} = [(H_j^y/H_I^y)/(W_j^{xz}/W_I^{xz})]^{1/2}$

β^y_{ij} = Shape factor between position i and j

H_j^y = Height of channel y at position j

H_i^y = Height of channel y at position i

W_j^{xz}= Width of channel xz at position j

W_I^{xz} = Width of channel xz at position I

(24). $H_4^y = (\beta^y_{1E}\beta^Y_{E3}\beta_{34})(\alpha^Y_{13}\,\alpha^Y_{34})^{1/2}.H^Y_1$

H_4^y = Height of channel y at position 4

β^y_{1E} = Shape factor for channel y between points 1 and E

β^Y_{E3}= Shape factor for channel y between points 3 and E

α^Y_{13}= Size factor for channel y between points 1 and 3

α^Y_{34} = Size factor for channel y between points 3 and 4

H^Y_1 = Height of channel y at position 1

(25). $W_E/W_1 = (H_E/H_1)^r$

W_E = Extrudate width at equilibrated swell state.

w_1 = Width at die.

H_E = Height of product at equilibrated swell state.

H_1 = Height of product at die.

r = Material dependant constant.

(26). $W_3/W_E = (H_3/H_E)^s$

W_E = Extrudate width at equilibrated swell state.

W_3 = Product width.

H_E = Height of extrudate at equilibrated swell state.

H_1 = Height of die.

s = Material dependant constant.

(27). $Q^y = W_1^{y}.(H_1^y)^2/F(n)\{H_1^y.\Delta P/(2m^*.L_1^y)\}^{1/n}$

Q^y = Volumetric out Put Across the Channel y.

W_1^y = Width of the Channel.

H_1^y = Height of the Channel.

F(n) = 2.(1/n+2)

ΔP = Pressure Drop Across the Channel.

m* = Rheological Parameters of the Melt.

L = Length of the Channel.

n = Power Law Index.

(28). $H_E/H_1 = [1 + p.(\tau)^q]^{1/4}$

p = Width of Slit at Product.

$\tau = \Delta P H_l/2L_l$, Shear Stress Applied in the Slit.

H_E = Height of Slit at Equilibrated Swell State

H_l = Height of Slit at Die

q = Constant.

(29). $\tau = \Delta P.H/2.L$

τ = Shear Stress

ΔP = Pressure Drop Applied Across the Flow channel.

H = Height of the Channel.

L = Length of the Channel.

(30). $\beta^{y}_{1E} = [\ (H_E^{y}/H_I^{y})/(W_E^{XZ}/W_I^{XZ})]^{1/2} = [\ 1+p(\tau^{y})]^{(1-r)/8}$

β_{IE}^{Y} = Shape Factor for Channel y, Between Points I & E.

p = Constant Depending on Rheological & Die Swell Properties.

τ^{Y} = Shear Stress Applied in Section Y.

r = Constant

(31). $\beta^{XZ}_{1E} = [\ (H_E^{XZ}/H_I^{XZ})/(W_E^{Y}/W_I^{Y})]^{1/2} = [\beta_{1E}^{Y}]^{-1}$

β_{E3}^{Y} = Shape Factor For Channel Y, Between Points E & 3.

α_{E3}^{Y}= Size Factor For Channel Y, Between Points E & 3.

s = Constant Depending on Rheological & Die Swell Properties.

(32). $\alpha_{1E}^{Y} = (\ 1+p.(\tau)^{q})^{(r+1)/4}$

α_{1E}^{Y} = Size Factor for Channel y.

p = Constant Depending on Rheological & Die Swell Properties.

q = Constant Depending on Rheological & Die Swell Properties.

r = Constant Depending on Rheological & Die Swell Properties.

(33). $\alpha_{13}^{Y} = \{H_1^{y}/(U_3.F(n))\}.\{\ \tau_Y/m^*\}^{1/n}$

α_{13}^{Y} = Size Factor for Channel y, between points 1 & 3.

H_1^{y} = Height of the Channel.

U_3 = Die Exit Velocity.

F(n) = 2.(1/n +2)

τ_Y = Shear Stress Applied in Channel Y.

m* = Constant.

n = Power Law Index.

(34). $\beta_{E3}^{Y} = [\alpha_{E3}^{Y}]^{(1-s)/2(s+1)}$

β_{E3}^{Y} = Shape Factor For Channel Y, Between Points E & 3.

α_{E3}^{Y}= Size Factor For Channel Y, Between Points E & 3.

s = Constant Depending on Rheological & Die Swell Properties.

(35). $\alpha_{E3}^{Y} = \alpha_{13}^{Y}/\alpha_{IE}Y$

α_{E3}^{Y} = Size Factor for Channel y, between points E & 3.

α_{13}^{Y} = Size Factor for Channel y, between points 1 & 3.

α_{IE}^{Y} = Size Factor for Channel y, between points 1& E.

(36). $H_3^{y}/ H_1^{y} = \beta_{IE}^{Y}\beta_{E3}^{Y}(\alpha_{13}^{Y})^{1/2}$

H_3^{y} = Product Thickness at Position Y.

H_1^{y} = Die Thickness at Position Y.

β_{IE}^{Y} = Shape Factor Between Die and Equilibrated State at Position Y.

β_{E3}^{Y} = Shape Factor Between Equilibrated State and Product at Position Y.

α_{13}^{Y} = Size Factor Between Die and Product at Position Y.

(37). $W_3^{XZ}/ W_1^{XZ} = \beta_{IE}^{XZ}\beta_{E3}^{XZ}(\alpha_{13}^{Y})^{1/2}$

W_3^{XZ} = Product Width at Position XZ.

W_1^{XZ} = Die Width at Position XZ.

β_{IE}^{XZ} = Shape Factor Between Die and Equilibrated State at Position XZ.

β_{E3}^{XZ} = Shape Factor Between Equilibrated State and Product at Position XZ.

α_{13}^{Y} = Size Factor Between Die and Product at Position Y.

(38). $\tau_{wall} = -p.\ \mu_{G}.\exp[(2\mu_G/R).(L-z)]$

R = Radius of the tube.

P_L = Melt pressure at distance L.

μ_G = Friction coefficient in slipping.

μ_H = Friction coefficient in adhesion.

τ_{crit} = Critical wall stress.

(39). $\Phi = (T_{(x,t)} - T_F)/(T_M - T_F)$

T_M = Melt temperature.

T_F = Cooling media temperature.

$T_{(x,t)}$= Temperature of the extrudate at x distance and at time t.

(40). $(T_{(x,t)} - T_F)/(T_M - T_F) = [2Sin\delta/(\delta + Sin\delta.Cos\delta)].e^{-\delta^2 at/D^2}.Cos(\delta.x/D)$

$T_{(x,t)}$ = Temperature at melt / frozen melt interface.

T_F = Temperature of Cooling Fluid.

T_m = Temperature of Melt.

δ = Dimensionless Parameter.

a = $\lambda/\rho.C_p$

t = Time Taken to Form a Required Thickness of Frozen Melt.

D = Wall Thickness of the Extrudate.

x = Thickness of Frozen Melt.

(41). $\alpha_h.D/\lambda = Bi$

α_h = Heat transfer coefficient

D = Wall thickness of the extrudate.

λ = Thermal conductivity.

Bi= Biot number

(42). $\delta = \alpha_h D/\lambda.\cot\delta$.

δ = Dimensionless Parameter.

α_h = Heat Transfer Coefficient

D = wall Thickness of the extrudate

λ = Thermal Conductivity

(43). $v(T) = 1/\rho(T)$

$v(T)$ = Volume of melt at temperature T.

$\rho(T)$ = Density of melt at temperature T.

(44). $\rho(T)=\rho(T_0) * 1/(1 + \alpha_t(T-T_0))$

α_t = Linear coefficient of thermal expansion

$\rho(T_0)$ = Density at the reference temperature T_0

$\rho(T)$ = Density at temperature T

(45). $L_2 = l_1 * (1 + \alpha_t \Delta T)$

ΔT = Temperature difference

α_t = Thermal expansion coefficient

L_2 = Length of extrudate at melt temperature.

l_1 = Length of solidified extrudate at room temperature.

(46). $\tau = \Delta P.H/2.L$

ΔP = Pressure Drop Across the Slit.

τ = Shear Stress Applied.

L = Length of Slit Channel.

H = Height of Slit Channel.

(47). $V_z = (\phi/m+2).(\Delta P/L)^m.(H/2)^{m+1}$

V_z = Average Velocity at the Slit.

ϕ = Proportionality Constant of Power Law Equation.

m = Power Law Index.

ΔP = Pressure Drop Across the Slit.

L = Length of Slit.

ANNEXTURE - C

LIST OF FIGURES

ANNEXTURE – D

DERIVATION OF PRESSURE DROP EQUATION FOR TAPERED CHANNELS; REF: EQUATION (13).

Pressure Drop for a Parallel Slit Channel;

$$\Delta P = 2\,\eta L(\xi+1)\{Q(4n+2)/n\}^n.\ \xi^{-(n+1)}.H^{-(3n+1)} \quad (13.1)$$

ξ = W/H , Shape Factor.
η = Viscosity of the Melt.
L = length of Slit.
Q = Volumetric Out Put.
n = Power Law Index.
H = Height of Slit.

Tapering rectangular Channel,

Consider a tapering channel of constant cross sectional rectangular shape. The height h,at any point along the length l,is defined by,

$$h = H_1 - 2.l.\tan\theta \quad (13.2)$$
$$\xi h = \xi H_1 - 2.l.\tan\phi \quad (13.3)$$

Where, θ and ϕ are the vertical and lateral taper angles.

Similarly, $\xi = \cot\theta/\cot\phi$,
From (A2), $dl = -(dh/2).\cot\theta$ (13.4)

Incremental Pressure drop dP is obtained by, substituting dl for L and h for H, and integration between limits H_1 & H_2 yields,

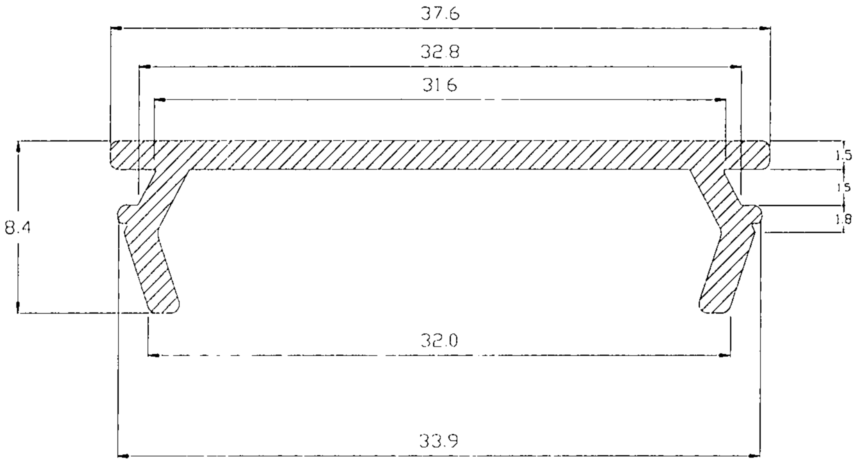
$$\Delta P = (\eta.\cot\theta/3)(\xi+1)\ \xi^{-(n+1)}\{Q.(4n+2/n)\}^n[H_2^{-3n} - H_1^{-3n}] \quad (13.5)$$

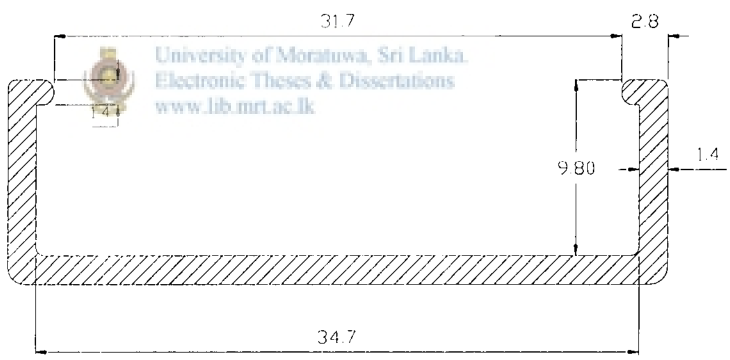
Taking ξ, as a constant, simplifying using binomial theorem gives, (A6);

$$\Delta P = [\eta.\cot\theta(Q(4n+2/W_1 n))^n][(H_2^{-2n}-H_1^{-2n})/2n^*(1+nH_1\cot\theta/W_1\cot\phi) + (H_2^{1-2n}-H_1^{1-2n})^*(n\cot\theta/W_1(1-2n)\cot\phi)] \quad (13)$$

ANNEXTURE - E

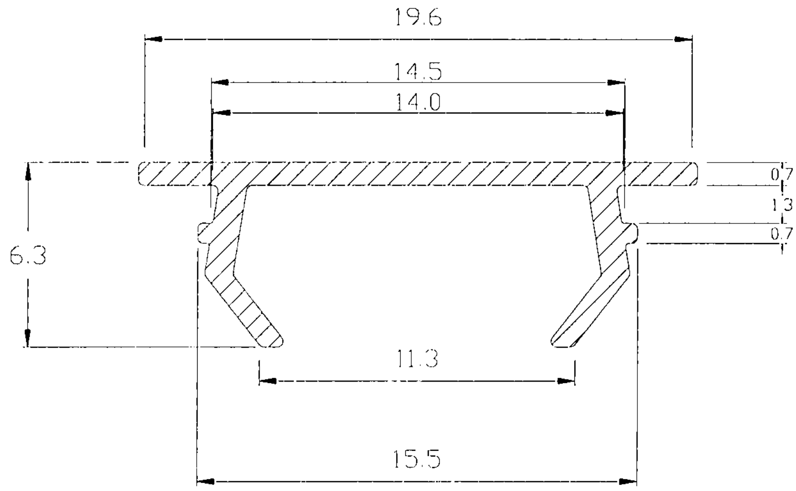
CROSS SECTION OF A TRUNKING PROFILE IN THE MARKET (BRAND A)

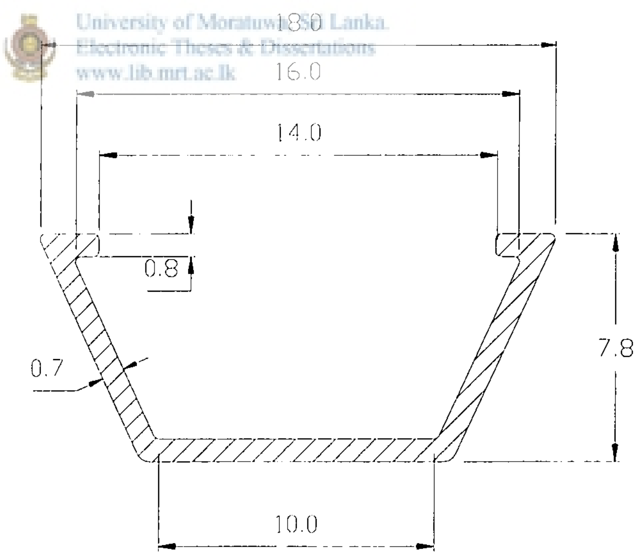




ANNEXTURE - F

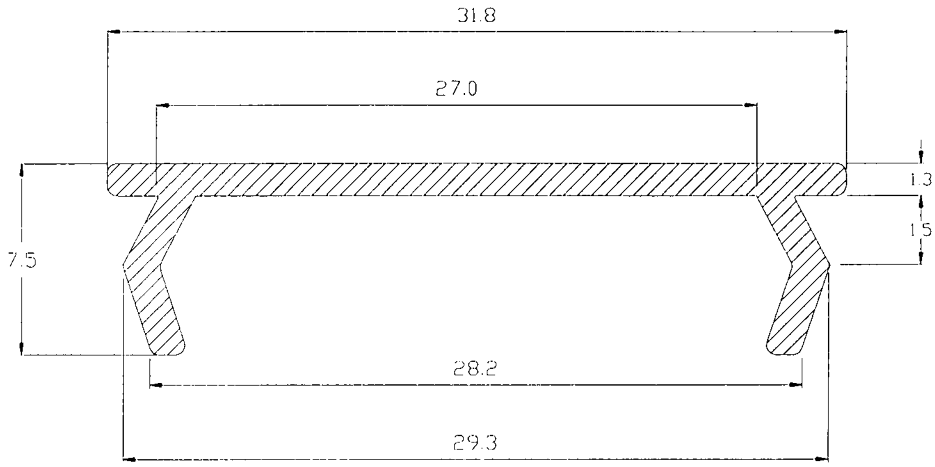
CROSS SECTION OF A TRUNKING PROFILE IN THE MARKET (BRAND B)

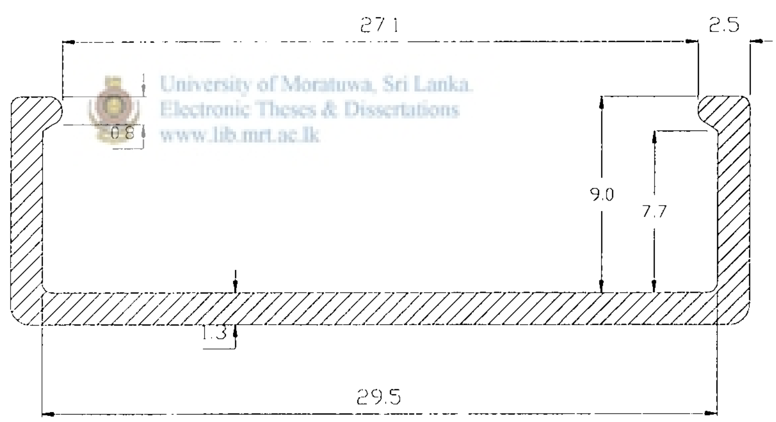




ANNEXTURE - G

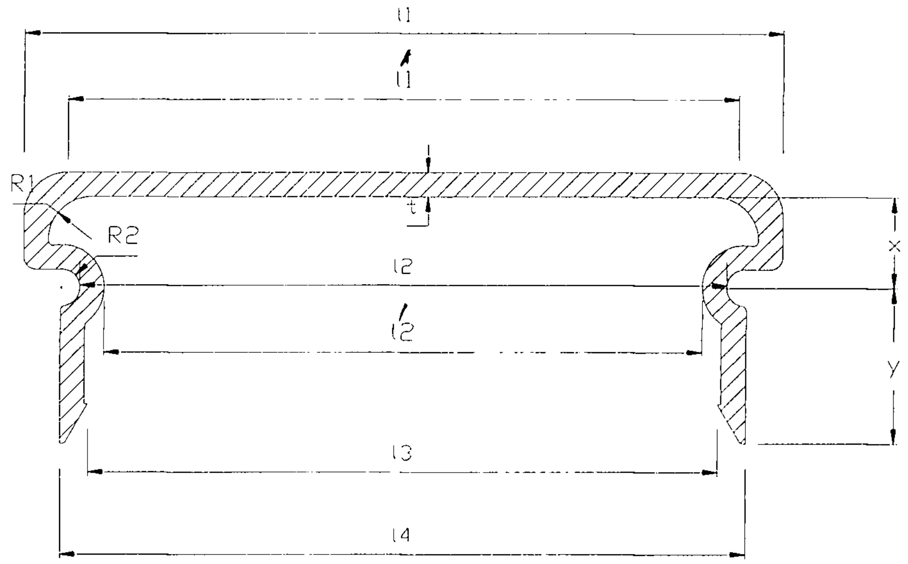
CROSS SECTION OF A TRUNKING PROFILE IN THE MARKET (BRAND C)





ANNEXTURE – H

DESIGNED PRODUCT DIMENSIONS & DRAWINGS

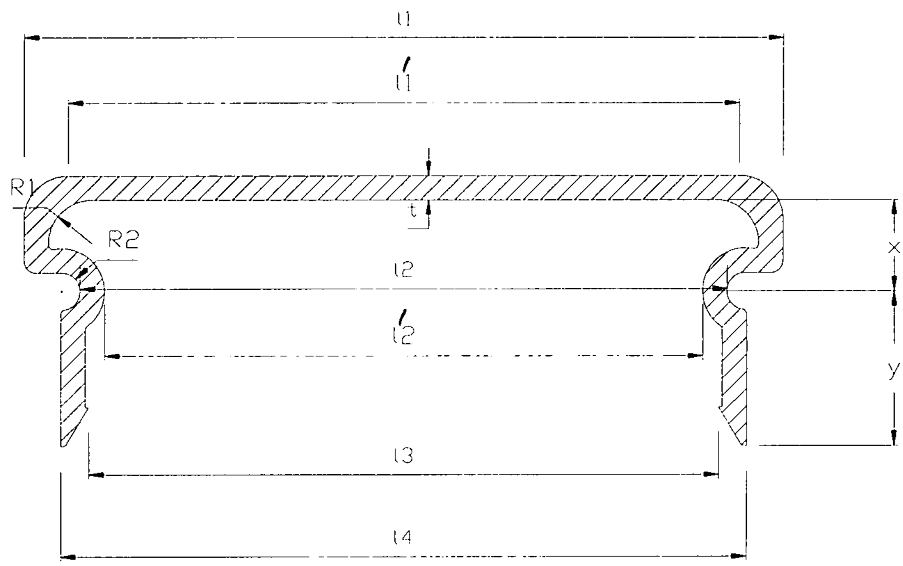


All dimensions are in mm

l_1	l_2	l_1'	l_2'	l_3	l_4
31.3	26.9	28.2	26.1	1.5	1.05

t	R_1	R_2	X	Y	
1.05	2.0	2.0	3.0	6.0	

ANNEXTURE – I
DESIGNED PRODUCT, DIE, CALIBRATOR DIMENSIONS



R1 – Outer Surface Radius
R2 – Inner Surface Radius

Units in mm

	Die	Equilibrated Swell State	Product
l1	31.28	31.33	31.30
l1'	29.22	29.17	29.20
l2	26.88	26.93	26.90
l2'	24.82	24.77	24.80
l3	28.22	28.17	28.20
l4	26.08	26.13	26.10
x	3.03	2.98	3.00
y	6.00	6.02	6.00
R1	2.00	1.98	2.00
R2	2.00	2.02	2.00
t	1.03	1.08	1.05

ANNEXTURE - **S**

APPROXIMATION OF PROFILE DIE DIMENSIONS TO A SLIT DIE.

1.0 Product Die Dimensions;

Width of Equivalent slit die, (Ref. Annex. - H)
= 2x{6.00 - 2.00 + 3.14x2.00 + 1/4x2x3.14x2.00}+29.2 - 2x2.0
= 2x{4.00 + 3.14(2+1)} + 25.20
= **52.04 mm**

Height of Equivalent slit die, (Ref. Annex - H)
= Thickness of the product.
= **1.05 mm**

2.0 Die Land Dimensions;

Width of Equivalent Slit Die = **52.14 mm**, (Ref. 6.3)

Height of Equivalent Slit Die = **1.03 mm**, (Ref. 6.3)

3.0 Die Dimensions, Parallel Section Before the Taper;

Width of Equivalent Slit Die = 52.04 + 7.05 mm (Ref. 8.0 & 6.0)
(Taper Angle 10^0) = **59.09 mm**

Height of Equivalent Slit Die = 1.05 + 7.05 mm (Ref. 8.0 & 6.0)
(Taper Angle 10^0) = **8.10 mm**

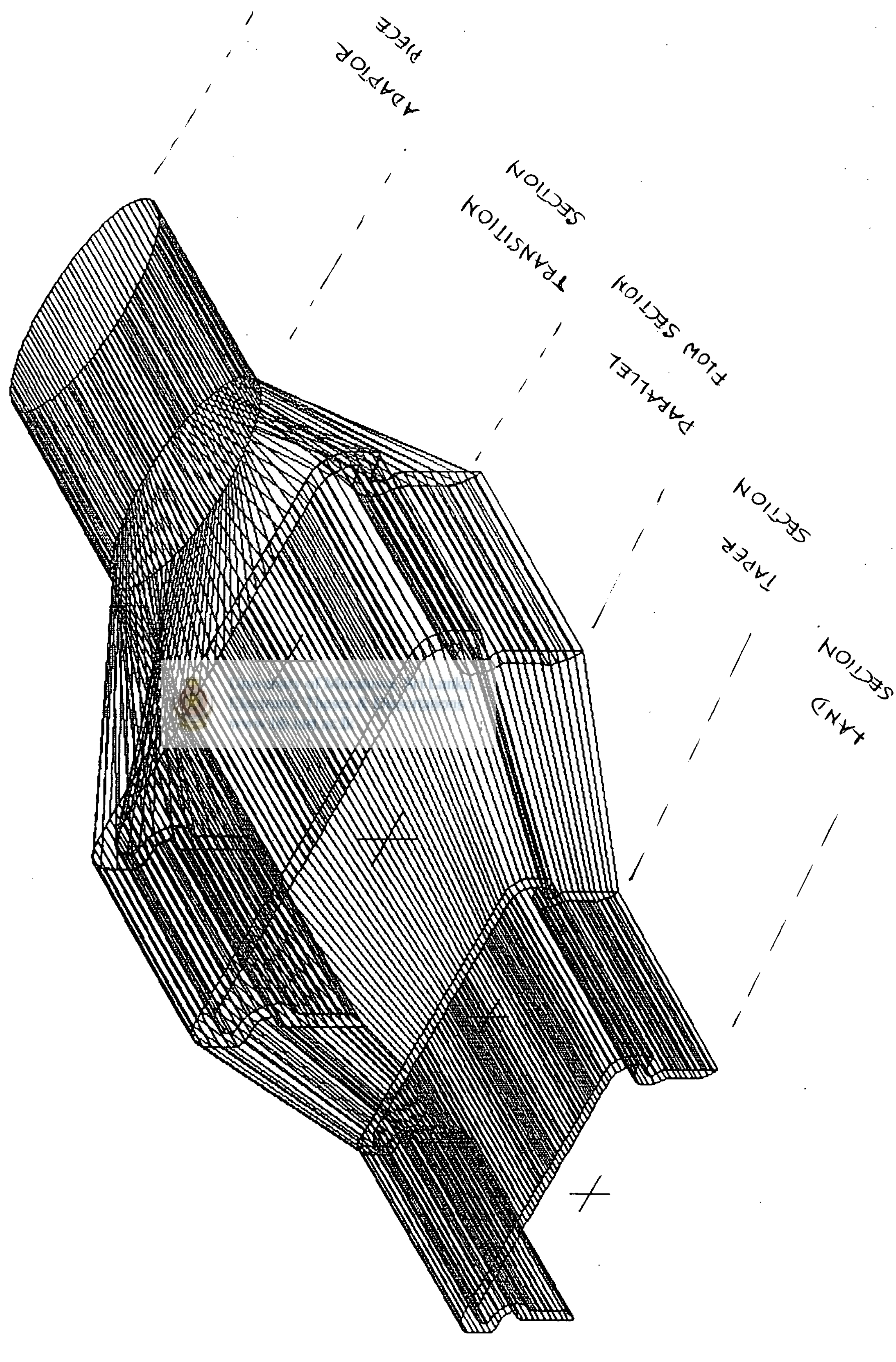
4.0 Equilibrated Swell State Slit Profile Dimensions;

Width of the Equilibrated Slit Die = **53.03 mm** (Ref. 6.3)

Height of the Equilibrated Slit Die = **1.07 mm** (Ref. 6.3)

ANNEXTURE-T

DIE LAYOUT OF THE DESIGNED PROFILE EXTRUSION DIE



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