MANUFACTURING WITH SILICONE RUBBER

A COMPREHENSIVE WORKSHOP

HCR Breakout Session

With Trail #1 and #2 Results Posted

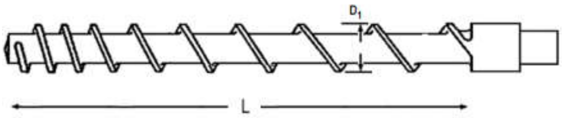
RDAbbott

Extrusion – L/D

L/D Ratio:

L/D = L/D_1 = Length Over Diameter Ratio

- Use an L/D 10:1 to 12:1 (Organics use as high as 20:1 to break the relatively high viscosity of the rubber)
- The higher the ratio the less efficient and the more work on the material and the greater the heat buildup.
- Too low of a ratio causes dimensional instability, porosity, and leakage backflow.



ARDL Extruder Specs:

L=30", $Lead_{bot}$=1 1/2"=3.81cm, $Lead_{top}$= 2", D1= 2 ½" = 6.35cm, D2=1 3/4"=4.44cm, RPM Max = 67, Sp.G. = 1.19g/cm^3

L/D = 30/2.5 = 12:1 (Best to be 10:1 to 12:1)

Extrusion – Mass Throughput Efficiency

Extruder Efficiency:

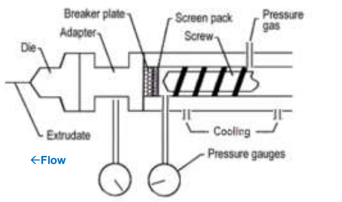
$M_{actual} = M_d - M_l$

M_d = Drag Mass Flow Determined by Calculation

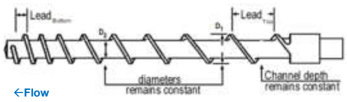
M_l = Leakage Mass Flow Determined by Experiment

Drag Mass Flow is moving the material forward dragging the material along the barrel with the screw flight movement. Cooling the barrel helps to improve drag flow. (Forward Movement)

Leakage Mass Flow is caused by the clearance of screw and barrel as a ratio to flow channel volume. The more worn the screw and barrel, the more leakage flow. (Backwards Movement)



Typical Extruder Design



Progressive Screw

NovationSi

25072801

Page 1 of 1

NovationSi
30 Second St SW
Barberton, OH 44203
(330)403-4444

Certificate of Analysis

Novation Product:	ARDL-HCE-60-T BLU	Customer:	ARDL
Customer Product:		Purchase Order No.:	SAMPLE
Lot Number:	25072801		
		Date of Manufacture:	8/19/2025
Quantity:	70 LBS	Date of Expiration:	11/19/2025

Characteristic	Value	Unit of Measure	Lower Limit	Upper Limit
RHEOMETER PER ASTM D5289 6 MIN @ 240 °F				
ML	1.38	LB-IN		REPORT
MH	17.66	LB-IN		REPORT
TS2	11.90	S		REPORT
TC90	51.30	S		REPORT
SLABS CURE 10 MIN @ 250°F				
Specific Gravity per ASTM D792	1.19	G/CC		REPORT
Durometer per ASTM 2240	61.0	Shore A		REPORT
Tensile Strength per ASTM D412	1427	PSI		REPORT
Elongation per ASTM D412	373	%		REPORT
Modulus 100%	339	PSI		REPORT
Tear Die B ASTM D624	121	PPI		REPORT

This is to certify the above designated material has been tested and did comply with the listed specifications when supplied in original container. It is solely the responsibility of the customer to determine the suitability of materials purchased from R.D. Abbott for your particular use or application.

Approved By

August 25, 2025
DATE

Extruder – Mass Throughput

Calculating Drag Mass Flow:

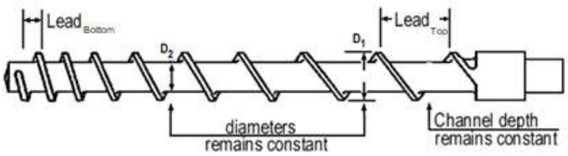
M_d = A_{fc} x Lead x Sp.G / rev

A_{fc} = Cross Sectional Area of the flow Channel in cubic centimeters = $\pi/4\ (D_1^2 - D_2^2)$

Lead = Lead length at end of screw in centimeters

RPM = Extruder speed in revolutions per minute

Sp.G. = Specific Gravity gr/cm^3 from CoA or TDS.



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A_{fc} = $\pi/4\ (6.35^2 – 4.44^2)$ = 16.2cm^2/rev

M_d = 16.2cm^2/rev x 3.81cm x 1.19 gr/cm^3 =

M_d = 73.4 gr/rev

This assumes:
No leakage backflow
No slippage backflow

Which means: 100% extruder efficiency

Extruder – Extrusion Efficiency

Extruder Efficiency:

Eff = M_{actual} / [M_d x RPM_{actual}]

M_{actual} = Eff x M_d = M_d - M_l

M_l = M_d (1 – Eff)

M_d = Drag Mass Flow

M_l = Leakage Mass Flow

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Leakage Mass Flow is caused by the clearance of screw and barrel as a ratio to flow channel volume. The more worn the screw and barrel, the more leakage backflow. (Backwards Movement)

ARDL Extruder Specs:
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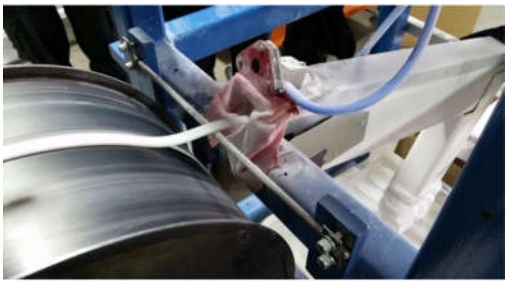
M_d = 73.4 gr/rev

If M_{actual} = 440.4g/min at 6rpm: Eff = 1.0
If M_{actual} = 440.4g/min at 12rpm: Eff = 0.5
If M_{actual} = 440.4g/min at 60rpm: Eff = 0.1

Extrusion Trail #1 – Production Rate - Economics



Trial #1: Production Rate

Extrusion Profile is a 12mm x 3mm rectangular strip.

Based on price with consideration of material, labor, and overhead Run at Rate is(assumes ~7hrs of operation per shift):

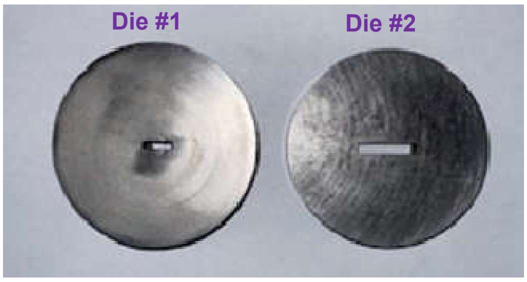
RatR: 4,000m/shift = 10m/min

Extrusion Trail #1 – Production Mass Throughput

Product Rate Calculation:

M_{prod} = A_{cs} x 100cm/m x Production Rate x Sp.G.

- Extrudate Cross Sectional Area (A_{cs}) is calculated by geometry of the extrudate dimensions.
- Specific Gravity in gr/cm^3 from CoA or TDS.



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Die #1 Extrudate A_{cs} : 12mm x 3mm = 36mm^2 = 0.36cm^2

M_{prod} = A_{cs} x 100cm/m x RatR (m/min.) x Sp.G.= 0.36cm^2 x 100 x 10 x 1.19

M_{prod} = 428gr/min. = 25.7 kgs/hr

Mass per meter = A_{cs} x 100cm/m x x Sp.G.= 0.36cm^2 x 100 x 1.19 = 42.8 gr/m

Extrusion Trail #1 – Test Extruder Speed

Test extruder speed to meet production rate:

$RPM_{test} = M_{prod} / M_d$

M_d = 73.4 gr/rev

M_{prod} = 428 gr/min.

RPM_{test} = 428g r/min. / 73.4 gr/rev

RPM_{test} = 6 rpm

Extrusion Trial #1 - Salt Bath – Residence Time

Residence Time:

Residence Time = Mass of Extrudate (gr/m) / Extrudate Rate (gr/minute) x Salt Bath Contact Length

- Residence time in the salt bath is an important factor in sizing. It can become the controlling factor of the maximum run at speed.

- The salt bath provides the heat for curing of the rubber and the cure time required must no exceed the residence time in the extruder.

ARDL Salt Bath Specs:
L= 25' Length = 7.62 meters

Workshop Example:

Knowing the Mass of Extrudate is 42.8 g/m

Measure the grams per minute coming off the extruder line and then calculate the Residence Time.

Last Year's Trial #1 Outcome- Worksheet

Station 1: Extruder

Determine Extrusion Rates at Various Extruder RPM Speeds - Set RPM from 6rpm to 30 rpm as indicated. Measure the weight of the extrudate per minute coming through the line by using a stopwatch and scale. Best to measure after ~3 minutes to reach steady output.

Calculate: [Weight (grams)] divided by [time (minute)] for each RPM setting

Record:

1. Actual RPM: ___5____ Obtained: __109___gr/minute (shoot for 6 rpm)
2. Actual RPM: ___8.9___ Obtained: __187___gr/minute (shoot for 10 rpm)
3. Actual RPM: ___17.0__ Obtained: __343___gr/minute (shoot for 15 rpm)
4. Actual RPM: ___20.2__ Obtained: __432___gr/minute (shoot for above 20 rpm)
5. Actual RPM: ___31.6__ Obtained: __744___gr/minute (shoot for above 35 rpm)

Q_{actual} at 5rpm = $Q_{(actual)}$ = 109g/min; Eff = 29.7%
Q_{actual} at 8.9rpm = $Q_{(actual)}$ = 187g/min; Eff = 28.6%
Q_{actual} at 17.0rpm = $Q_{(actual)}$ = 343g/min; Eff = 27.5%
Q_{actual} at 20.2rpm = $Q_{(actual)}$ = 432g/min; Eff = 29.1% ← **RatR**
Q_{actual} at 31.6rpm = $Q_{(actual)}$ = 744g/min; Eff = 32.1%

Exercise: Estimate the minimum RPM to obtain the needed for the economic RatR (Help: $M_{prod} = A_{cs}$ x 100cm/m x Production Rate (m/min.) x Sp.G

= ___428___gr/minute: **Station 2: Salt Bath**

Determine Salt Bath Residence Time and State of Cure - Knowing the extrusion is 42.8 gr/m (previously calculated in class) divided by Extrusion Rate times the bath contact length (7.62 meters), estimate the residence time for each rpm speeds

Calculate: Mass per meter of extrudate = Acs x 100cm/m x x Sp.G.= 0.36cm2 x 100 x 1.19 = _____42.8_____ gr/m

Calculate: Residence Time = 42.8gr/m / <gr/minute> x 7.62m

Record: Have the Operator check Salt Bath Temperature: Salt Temperature ___380____°F

1. Residence Time: ___16___ Obtained: ___2___ (0 = Gummy, 1 = Cured, or 2 = Cured with low surface tack)
2. Residence Time: ___8.7___ Obtained: ___2___ (0 = Gummy, 1 = Cured, or 2 = Cured with low surface tack)
3. Residence Time: ___4.7___ Obtained: ___2___ (0 = Gummy, 1 = Cured, or 2 = Cured with low surface tack)
4. Residence Time: ___3.7___ Obtained: ___2___ (0 = Gummy, 1 = Cured, or 2 = Cured with low surface tack)
5. Residence Time: ___2.2___ Obtained: ___0___ (0 = Gummy, 1 = Cured, or 2 = Cured with low surface tack) ← **Minimum Residence Time**

Exercise: Estimate the minimum residence time required to make sure the extrudate is fully cured based on results obtained above

Extrusion Worksheet – Trial #1

Station 1: Extruder

Determine Extrusion Rates (gr/minute) with a range of extruder speeds - Measure the weight of the extrudate per minute coming through the line by using a stopwatch and scale. Best to measure after ~3 minutes to reach steady output.

Calculation: [Weight (grams)] divided by [time (minute)] for each RPM setting

Record: ==

1. **Actual RPM: ____6_____ Obtained: ___134.5_______gr/minute (shoot for 6 rpm)**
2. **Actual RPM: ____10_____ Obtained: ___163______gr/minute (shoot for 10 rpm)**
3. **Actual RPM: _____20____ Obtained: _____763.4_____gr/minute (shoot for 20 rpm)**
4. **Actual RPM: _____30____ Obtained: _____808_____gr/minute (shoot for 30 rpm)**

M_{actual} at 6rpm = 134.5g/min; Eff = 30%
M_{actual} at 10rpm = 163g/min; Eff = 22%
M_{actual} at 20rpm = 763g/min; Eff = 52%
M_{actual} at 30rpm = 808g/min; Eff = 37%

Exercise: Estimate the minimum RPM to obtain the needed RatR:

M_{prod} = Acs x 100cm/m x Production Rate (m/min.) x Sp.G = ___428_____gr/minute:

Station 2: Salt Bath

Determine Salt Bath Residence Time (seconds) and State of Cure (raking) from the extruder output in station 1 – First calculate the mass of the extrudate per meter. Then calculate the residence time in the salt bath for each extruder RPM setting. The salt bath contact length is 7.62 meters).

Calculation: Mass per meter of extrudate = Acs x 100cm/m x x Sp.G.= ___42.8______gm/m

Calculation: Residence Time = <gr/m> / <gr/minute> x 7.62m

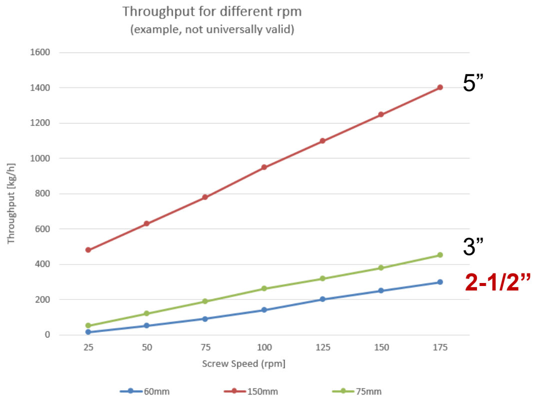
Record: Have the Operator check Salt Bath Temperature: Salt Temperature ____400_______°F

(0 = Gummy, 1 = Cured, or 2 = Cured with low surface tack)

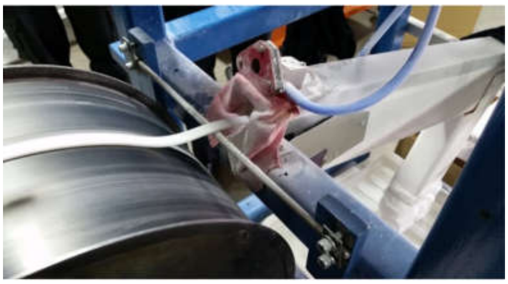
1. **Residence Time: ___2.42______ Obtained: ___2___**
2. **Residence Time: ____2.00_____ Obtained: ___2___**
3. **Residence Time: ___0.43______ Obtained: ___2___**
4. **Residence Time: __0.40_______ Obtained: ___2___** ← **Minimum Residence Time**

Exercise: Estimate the minimum residence time required to make sure the extrudate is fully cured based on results obtained above.

Extrusion – Extruder Throughput and Efficiency



Extrusion Trail #2 – Production Rate - Economics



Trial #1: Production Rate

Extrusion Profile is a 24mm x 4mm rectangular strip.

Based on price with consideration of material, labor, and overhead Run at Rate is(assumes ~7hrs of operation per shift):

RatR: 1,400m/shift = 3.5m/min

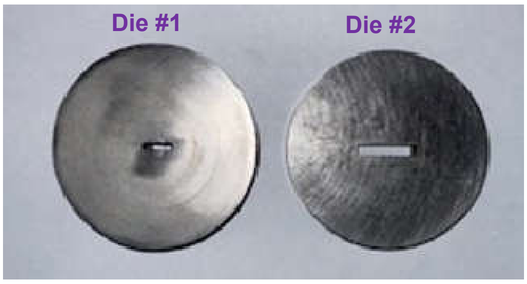
Extrusion Trail #2 – Production Mass Throughput

Product Rate Calculation:

$M_{prod} = A_{cs}$ x 100cm/m x Production Rate x Sp.G.

-Extrudate Cross Sectional Area (A_{cs}) is calculated by geometry of the extrudate dimensions.

-Specific Gravity in gr/cm^3 from CoA or TDS.



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Die #2 Extrudate A_{cs} : 24mm x 4mm = $96mm^2$ = $0.96cm^2$

$M_{prod} = A_{cs}$ x 100cm/m x RatR (m/min.) x Sp.G.= $0.96cm^2$ x 100 x 3.5 x 1.19

M_{prod} = 400gr/min. = 24.0 kgs/hr

Mass per meter = A_{cs} x 100cm/m x x Sp.G.= $0.96cm^2$ x 100 x 1.19 = 114 gr/m

Extrusion Trail #2 – Test Extruder Speed

Test extruder speed to meet production rate:

$RPM_{test} = M_{prod} / M_d$

M_d = 73.4 gr/rev

M_{prod} = 400 gr/min.

RPM_{test} = 400g r/min. / 73.4 gr/rev

RPM_{test} = 5.5 rpm

But we know the efficiency of this extruder is about 30% based on trial #1. Therefore, M_{prod} should be abo

RPM_{RatR} = 5.5 rpm /eff. = 5.5 / .3

RPM_{RatR} = 18.3 rpm

Extrusion Trial #2 - Salt Bath – Residence Time

Residence Time:

Residence Time = Mass of Extrudate (gr/m) / Extrudate Rate (gr/minute) x Salt Bath Contact Length

- Residence time in the salt bath is an important factor in sizing. It can become the controlling factor of the maximum run at speed.
- The salt bath provides the heat for curing of the rubber and the cure time required must no exceed the residence time in the extruder.

ARDL Salt Bath Specs:
L= 25' Length = 7.62 meters

Workshop Example:
Knowing the Mass of Extrudate is 114 g/m

Measure the grams per minute coming off the extruder line and then calculate the Residence Time.

Extrusion Worksheet – Trial #2

Station 1: Extruder

Determine Extrusion Rates (gr/minute) with a range of extruder speeds - Measure the weight of the extrudate per minute coming through the line by using a stopwatch and scale. Best to measure after ~3 minutes to reach steady output.

Calculation: [Weight (grams)] divided by [time (minute)] for each RPM setting

Record:

1. Actual RPM: ____6_____ Obtained: ___144.4______gr/minute (shoot for 6 rpm)

2. Actual RPM: ____10_____ Obtained: ___171.3_____gr/minute (shoot for 10 rpm)

3. Actual RPM: _____20____ Obtained: _____523.3_____gr/minute (shoot for 20 rpm)

4. Actual RPM: _____30____ Obtained: _____911.2_____gr/minute (shoot for 30 rpm)

M_{actual} at 6rpm = 144g/min; Eff = 33%
M_{actual} at 10rpm = 171g/min; Eff = 23%
M_{actual} at 20rpm = 523g/min; Eff = 36%
M_{actual} at 30rpm = = 911g/min; Eff = 41%

RatR

Exercise: Estimate the minimum RPM to obtain the needed RatR:

M_{prod} = Acs x 100cm/m x Production Rate (m/min.) x Sp.G = __400_____gr/minute:

Station 2: Salt Bath

Determine Salt Bath Residence Time (seconds) and State of Cure (raking) from the extruder output in station 1 – First calculate the mass of the extrudate per meter. Then calculate the residence time in the salt bath for each extruder RPM setting. The salt bath contact length is 7.62 meters).

Calculation: Mass per meter of extrudate = Acs x 100cm/m x x Sp.G.= ___114______gm/m

Calculation: Residence Time = <gr/m> / <gr/minute> x 7.62m

Record: Have the Operator check Salt Bath Temperature: Salt Temperature ____400_______°F

(0 = Gummy, 1 = Cured, or 2 = Cured with low surface tack)

1. Residence Time: ___6_____minutes Obtained: __2____

2. Residence Time: ____5____ minutes Obtained: __2____

3. Residence Time: ___1.66_____ minutes Obtained: __2____ ⟵ **Minimum Residence Time**

4. Residence Time: __.95______ minutes Obtained: ___1___

Exercise: Estimate the minimum residence time required to make sure the extrudate is fully cured based on results obtained above.