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# A Practical Approach to Scale-up from Bench-top Twin-screw Extruders

Alan Swanborough

Sales & Marketing Director

PRISM Products

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| | |
|---|---|
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| **Capabilities** | ▪ Complete portfolio<br>▪ World-class technologies<br>▪ Commercial reach |
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# Introduction

1. Twin screw melting and Mixing Process

2. 16mm and 24mm twin screw compounders.

3. Use of Specific Energy Input to predict performance

4. Relationship between screw speed and feed rate and their effect on :-
    - Energy Input
    - Residence Time
    - Degree of Fill

5. Scale-up and heat transfer

# Twin Screw Processing

1. **Twin screw melting and Mixing Process**

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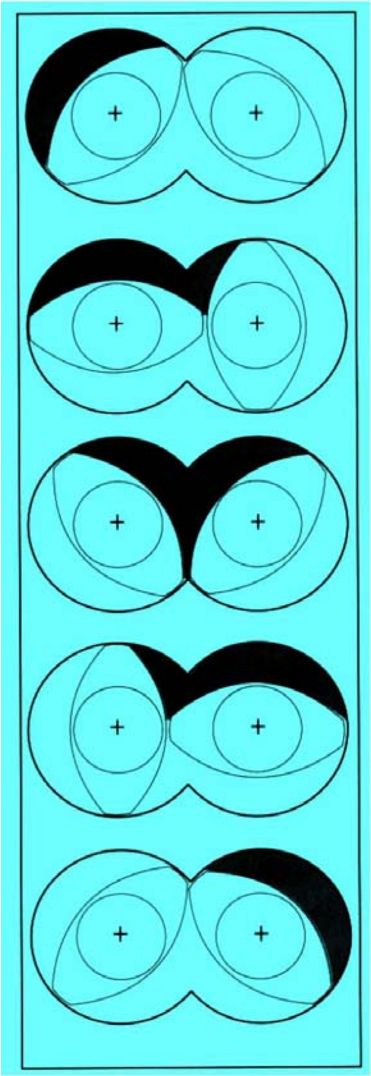
# Simple extrusion – Chinese take-away

# Twin-screw Mixing



TWIN-SCREW MIXING

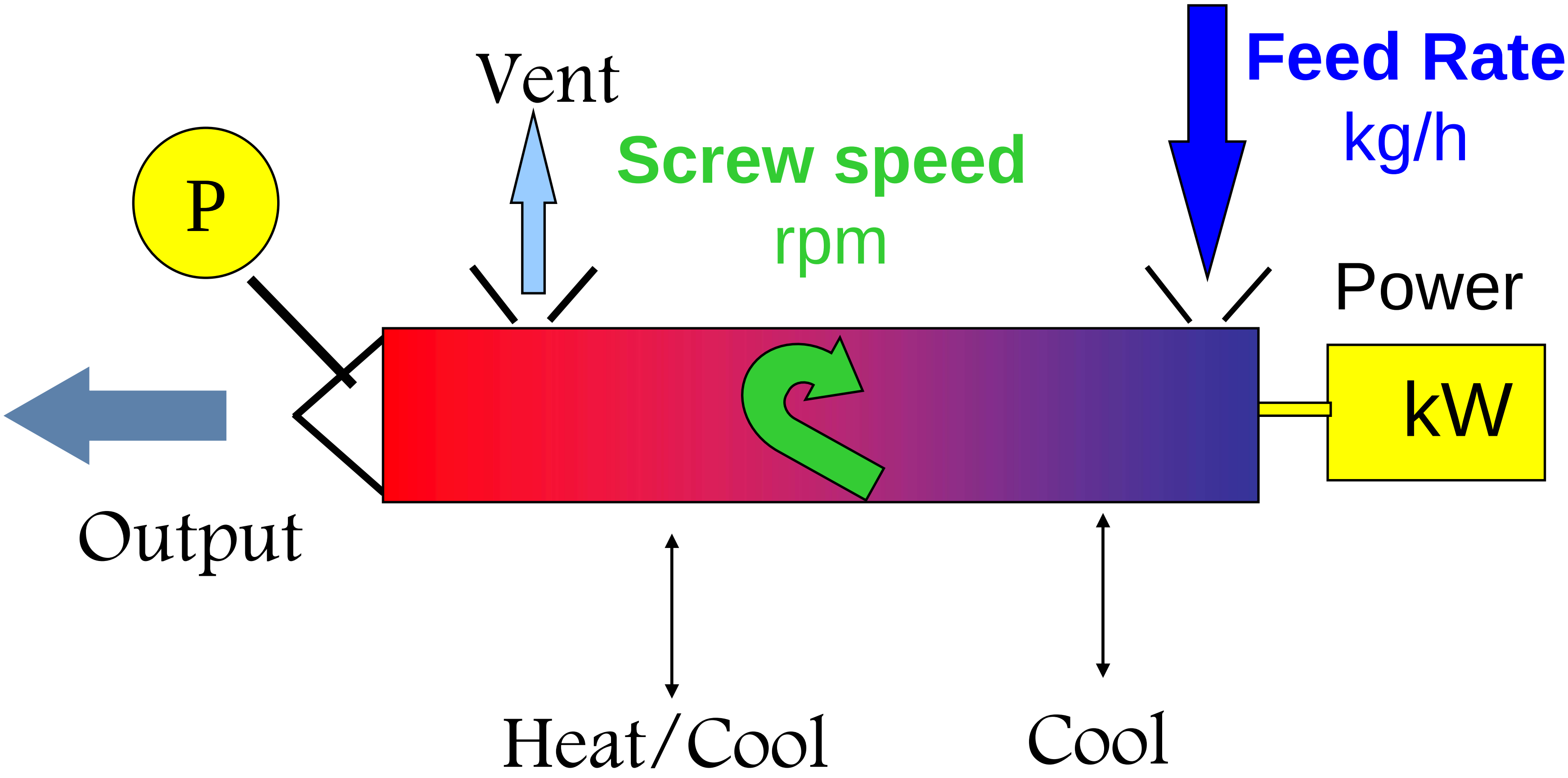
Material follows a figure '8' path as it is constantly transferred from one screw to the other across the intermesh.

The mixing action is a combination of compression and expansion with smearing effects between screw to screw and screw to barrel wall

The energy to melt the polymer comes from the mechanical energy of the shafts, (i.e. from the motor)

Inter-particulate friction causes rapid melting, and high shear is imparted during the high viscosity transition from solid to molten phase.

# Twin Screw Compounding



# Variables in Twin Screw Processing

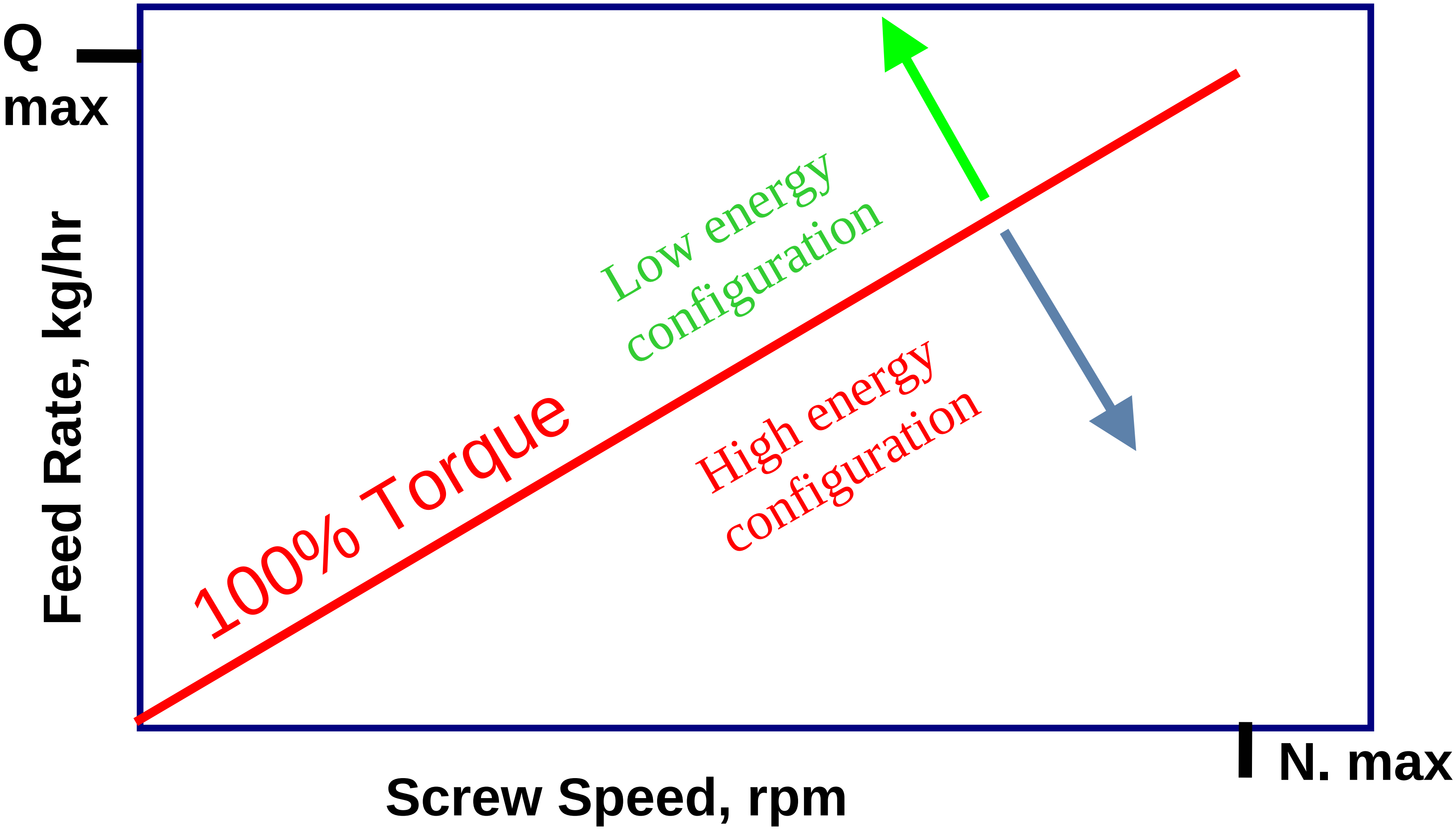
**Independent variables**

- **Continuous**
  - **Primary**: **Screw speed**, **Feed rate**
  - **Secondary**: **Barrel temp**
- **Step change**: **Screw design**, **Die design**, **Barrel layout**

**Dependent variables**

- **Process parameters**: **Shear Rate**, **Temperature**, **Residence Time**
- **Quality Control parameters**: **Dispersion**, **Colour**, **Degradation**

# Twin Screw Torque

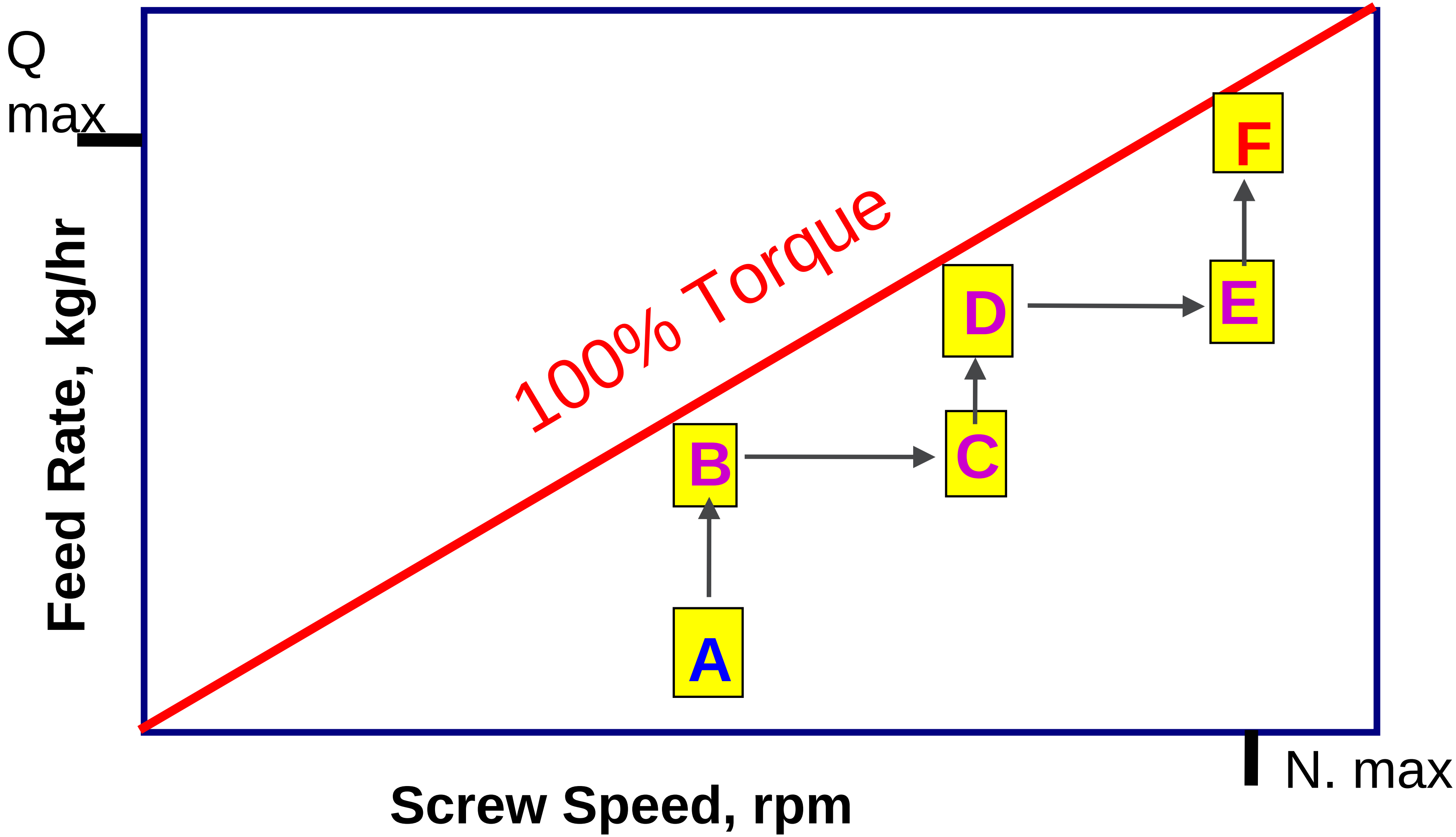


# Segmented Twin Screw Elements

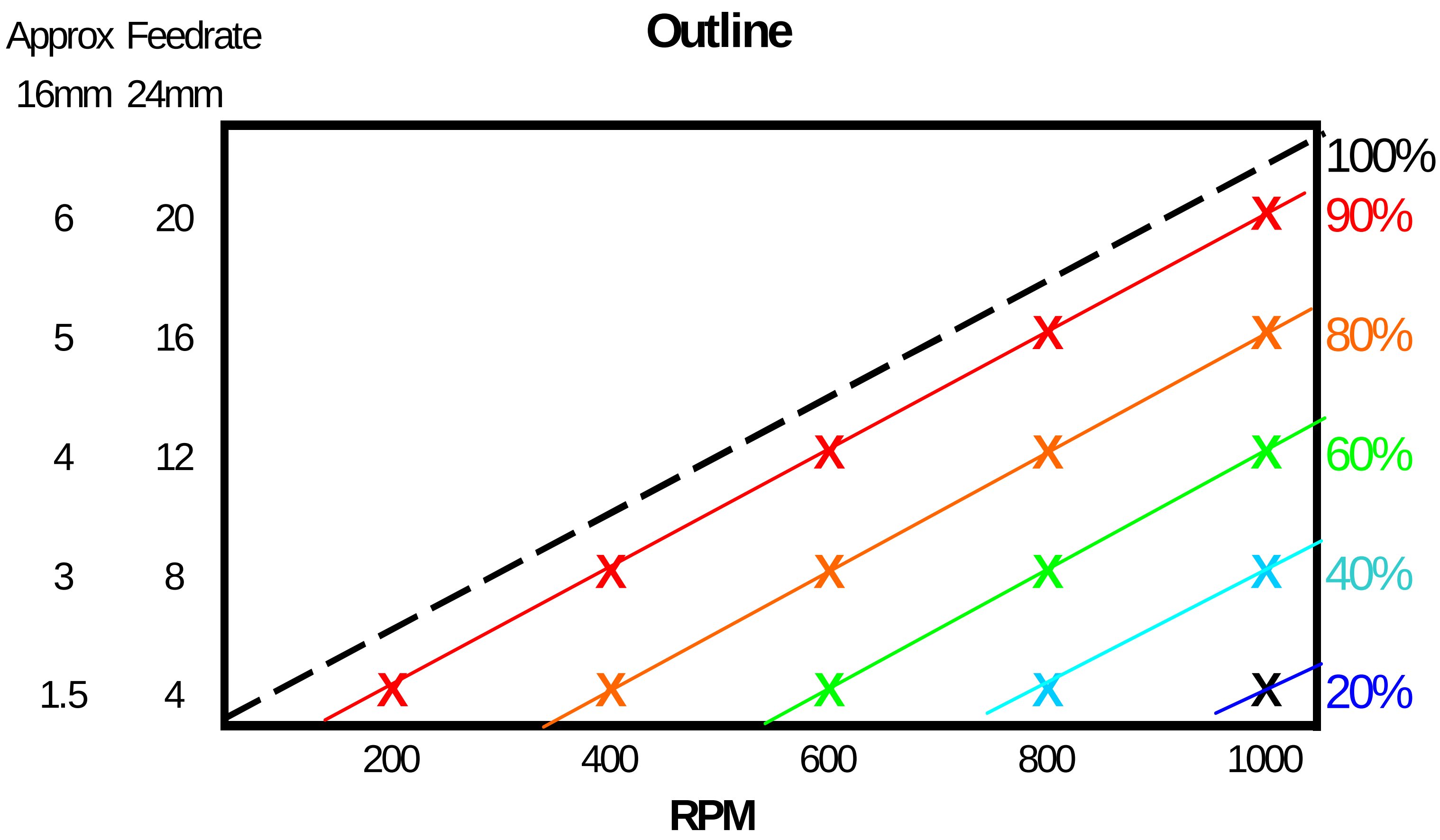
# Standard Twin Screw Elements

| | CONVEYING | MIXING |
|---|---|---|
| **Feed Screws** | ++++++++ | + |
| **30 deg Forward** | +++++ | ++ |
| **60 deg Forward** | ++++ | +++++ |
| **90 deg Alternate** | zero | ++++++++ |
| **60 deg Reverse** | - - - - | ++++++ |
| **Reverse Feed Screw** | - - - - - - - - | ++ |

# Twin Screw Primary Variables



# Experimental outline



# Equipment

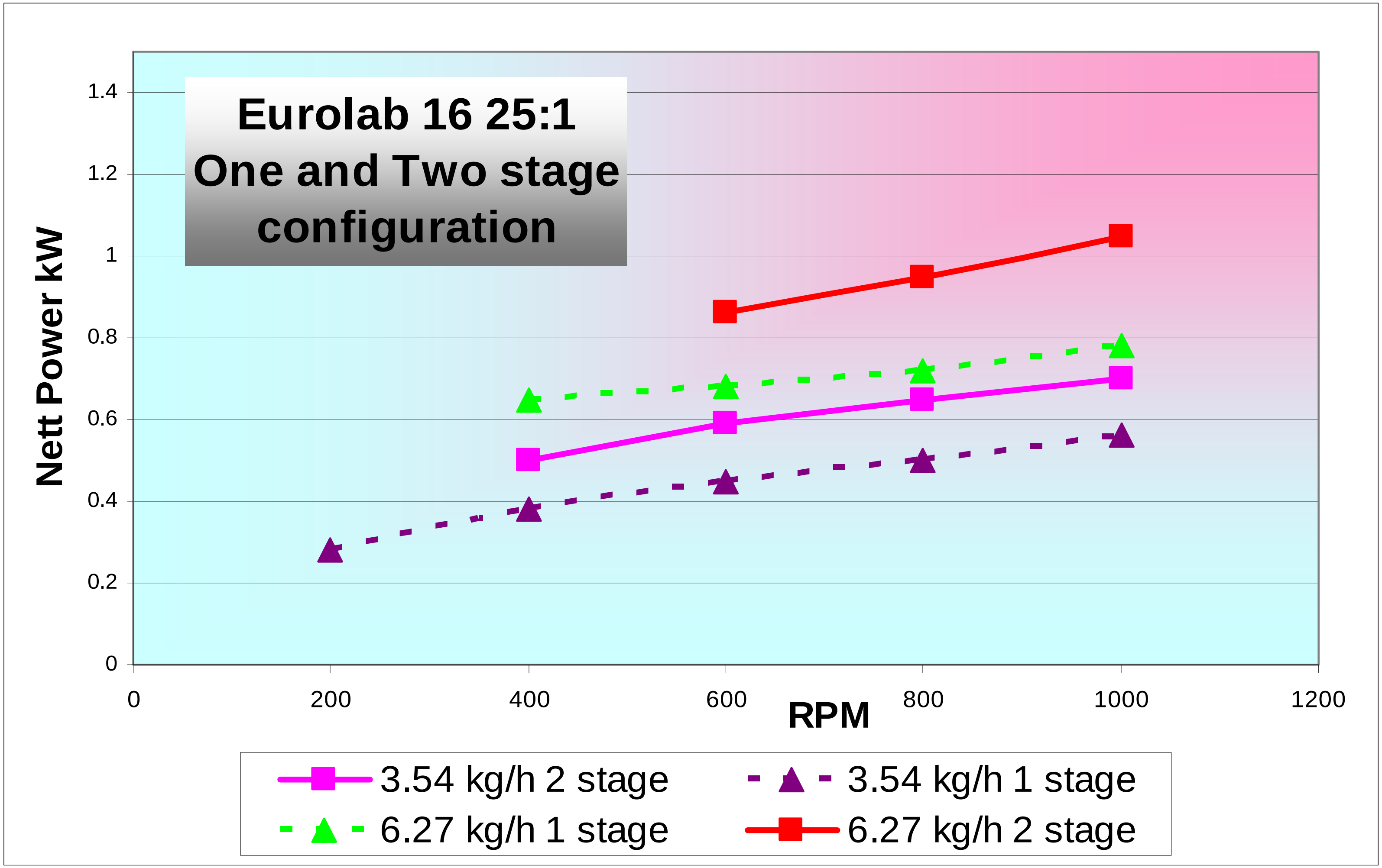
1. Twin screw melting and Mixing Process
2. **16mm and 24mm twin screw compounders.**
3. Use of Specific Energy Input to predict performance
4. Relationship between screw speed and feed rate and their effect on :-
   - Energy Input
   - Residence Time
   - Degree of Fill
5. Scale-up and heat transfer

# Experimental equipment

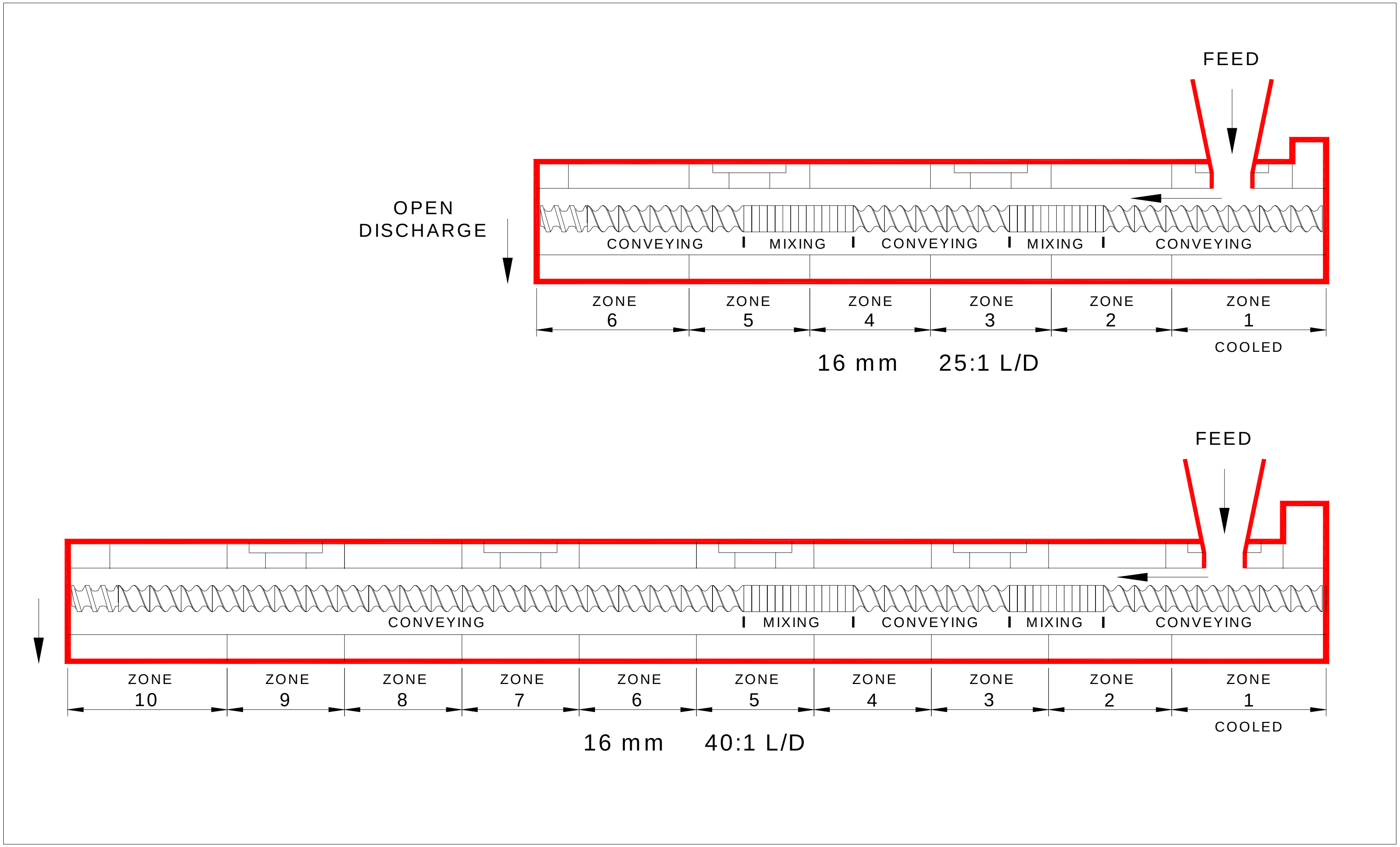
**PRISM co-rotating twin screw compounders.**

| Model | Screws | Power | RPM | L/D ratio |
|---|---|---|---|---|
| **Eurolab 16** | **16mm** | **2.5 kW** | **1,000** | **25:1 & 40:1** |
| **TSE 24 HC** | **24mm** | **9.0 kW** | **1,000** | **28:1 & 40:1** |

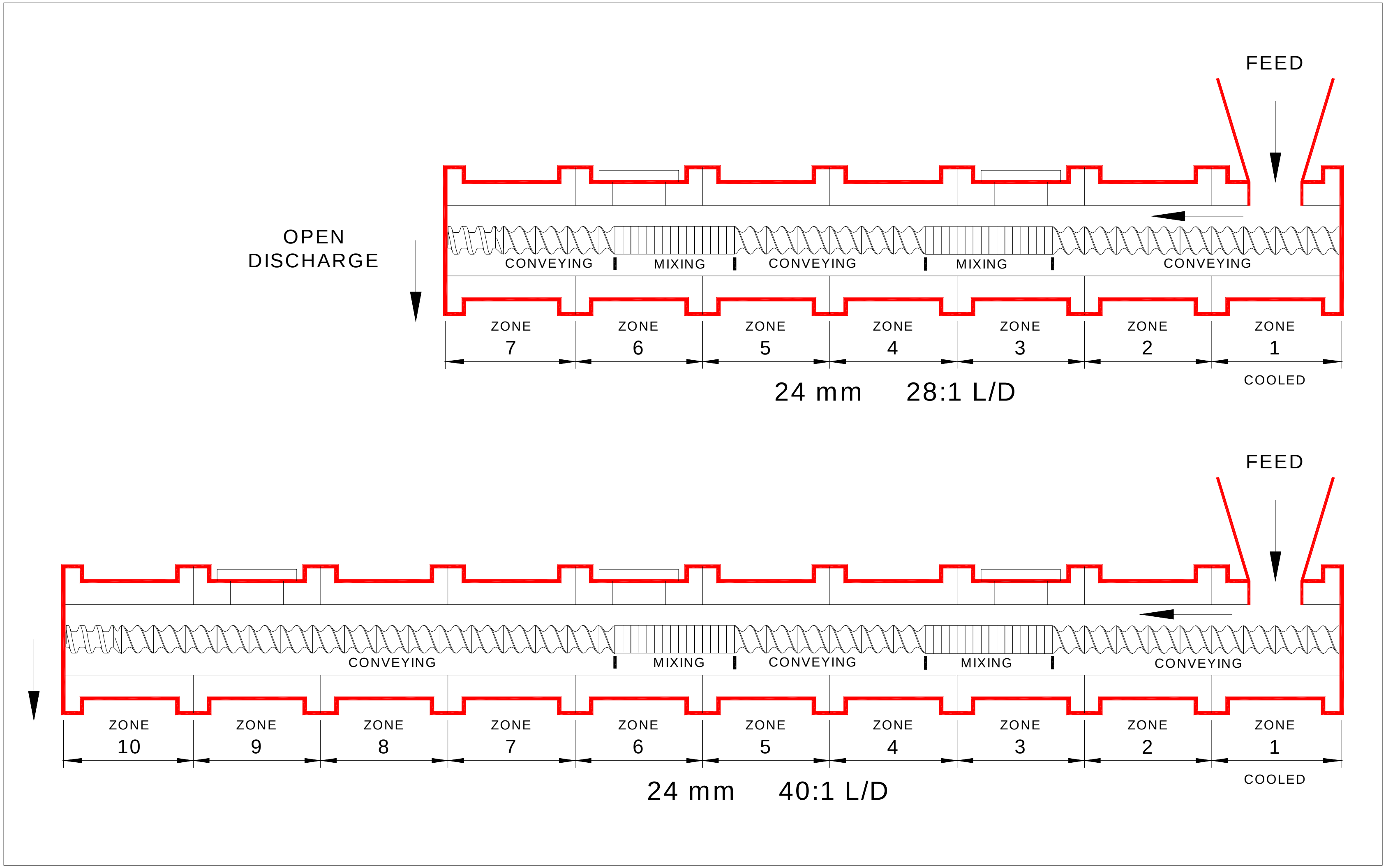
# Twin screw configurations 16mm



# Twin screw configurations 16mm



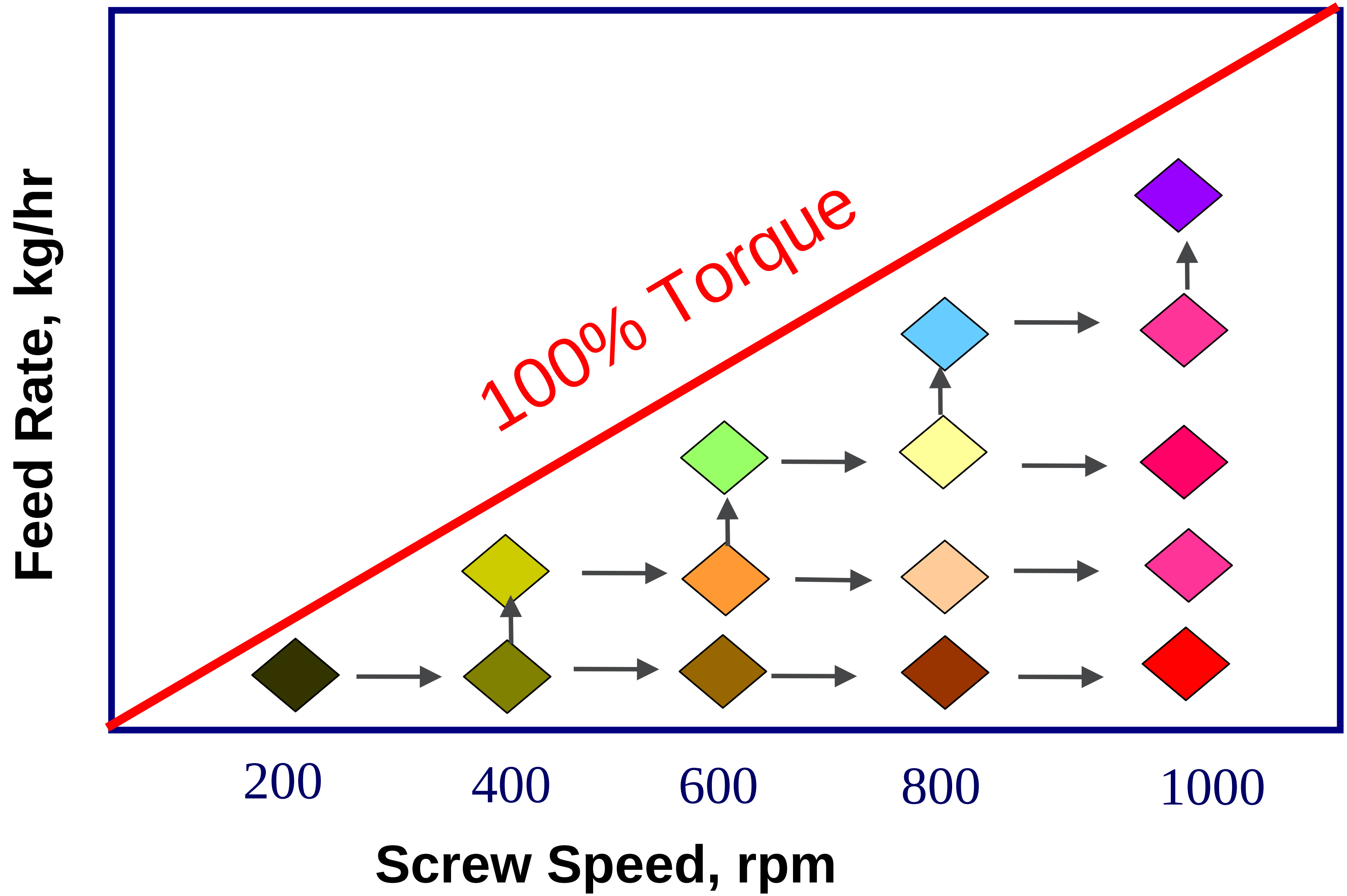
# Twin screw configurations 24mm



# PRISM Eurolab 16 extruder

# PRISM TSE 24 HC extruder

# Experimental procedure



# Specific Energy Input

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# Specific Energy Input

**The Specific Energy input is the measure of how motor power is converted into energy in the polymer**

**Motor power minus “no-load” power = P ( kW )**

**Polymer feed rate = Q ( kg/h )**

**Specific energy input = P/Q = E (kWh/kg)**

# Scale-up by Specific Energy Input

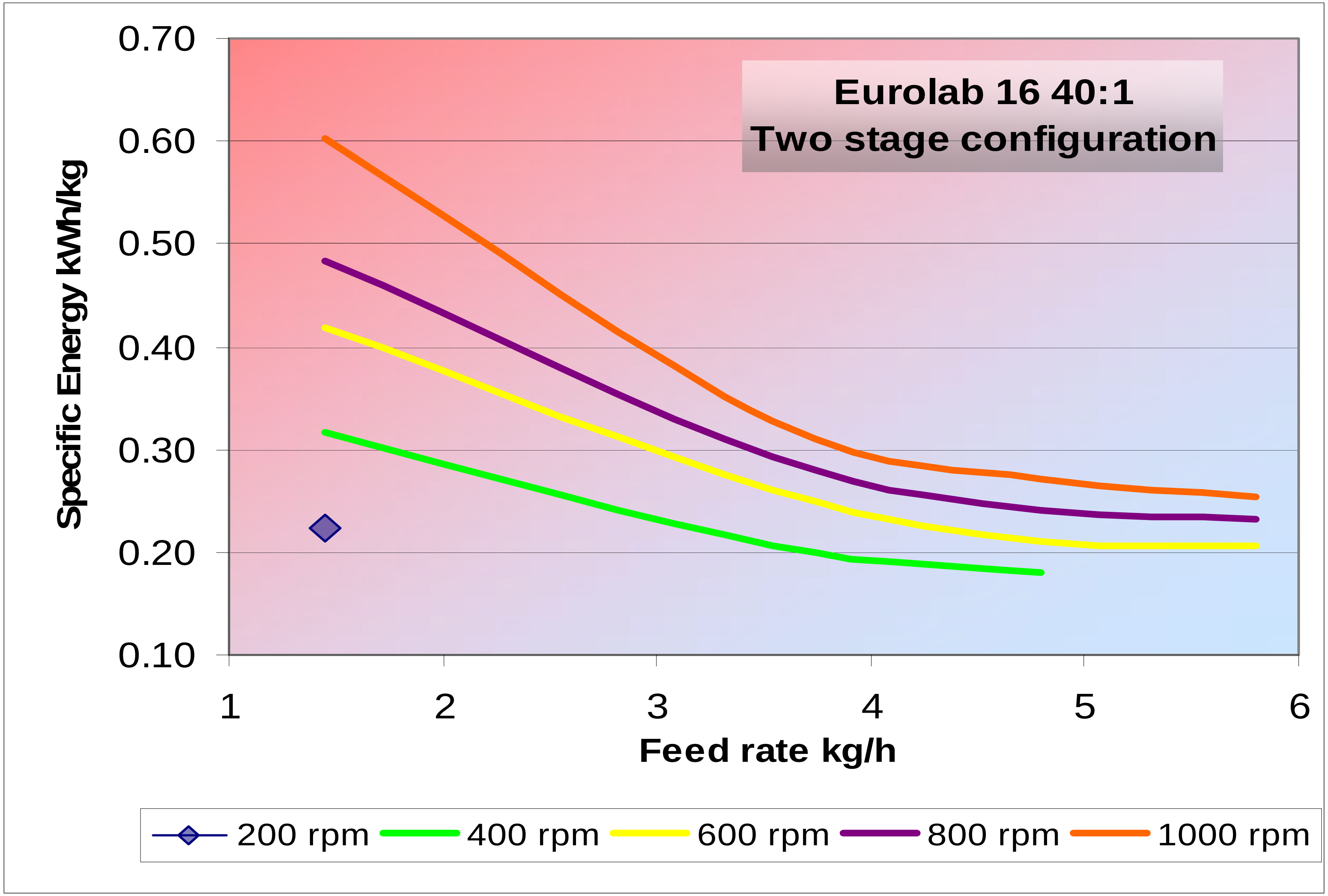
**The Specific Energy value allows a calculation of what motor power is required to process a defined quantity of Material.**

**Required Polymer Output = Q ( kg/h )**

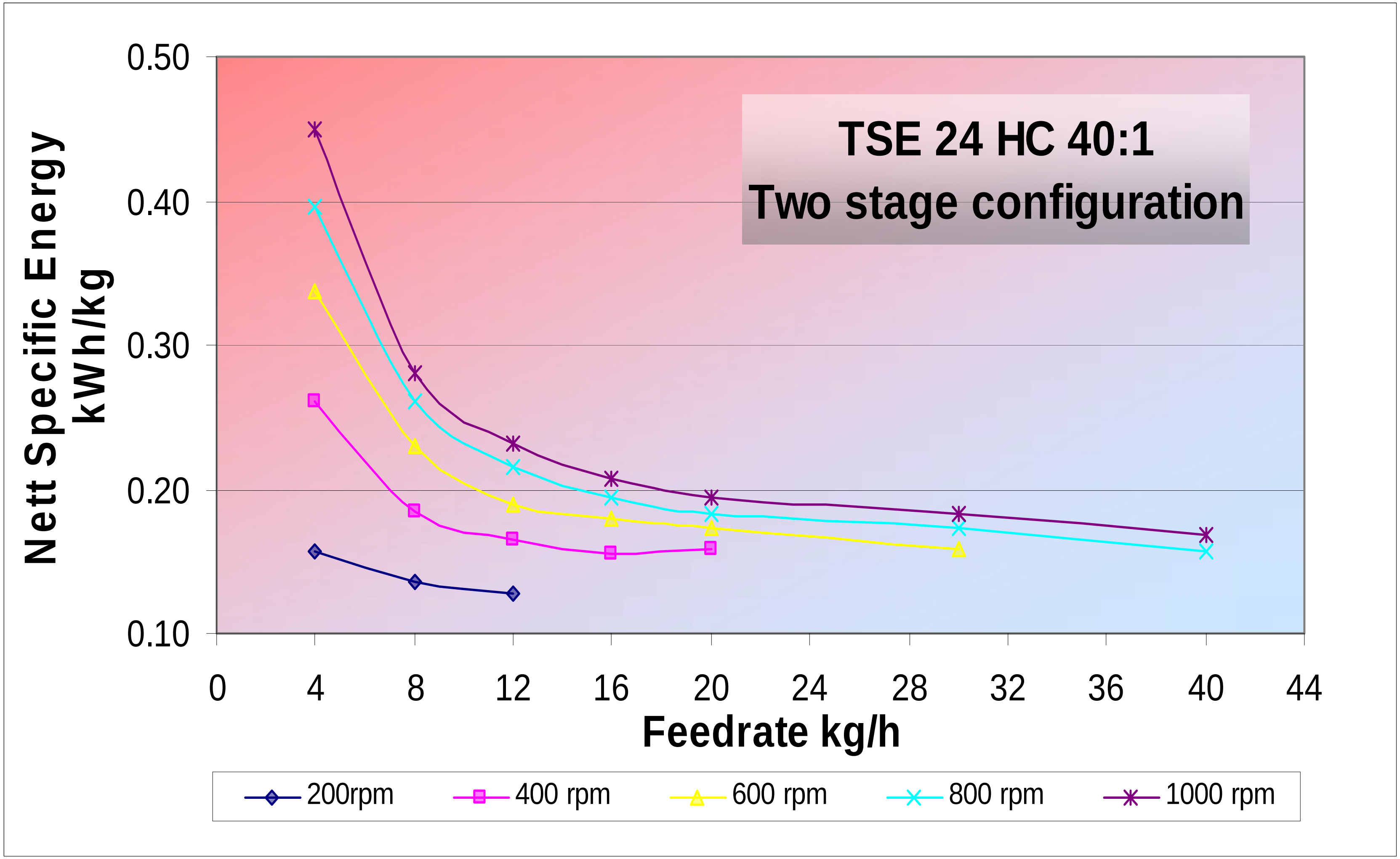
**Specific energy input = E (kWh/kg)**

**Nett Motor power P = Q x E ( kW )**

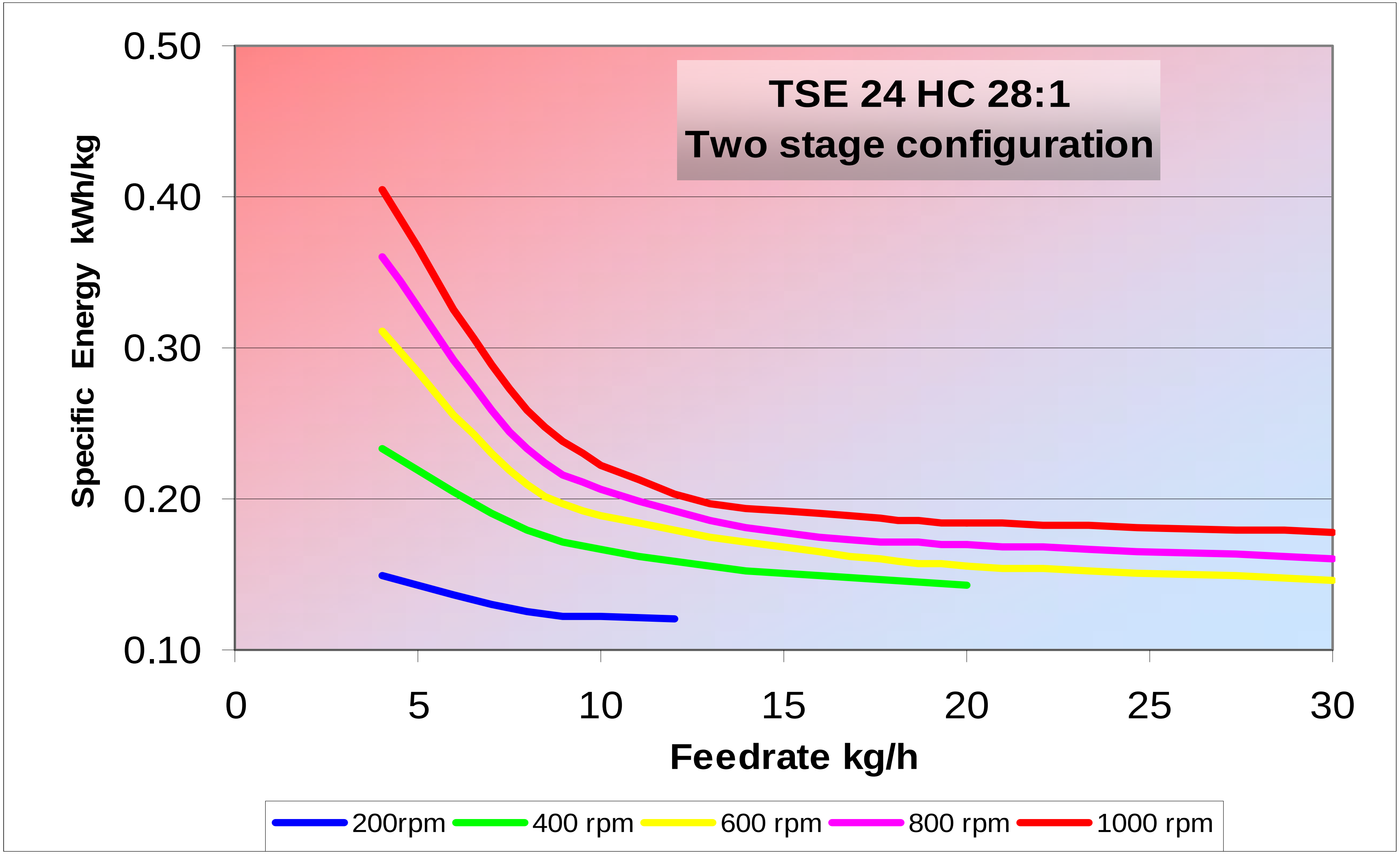
# Specific Energy in a twin-screw



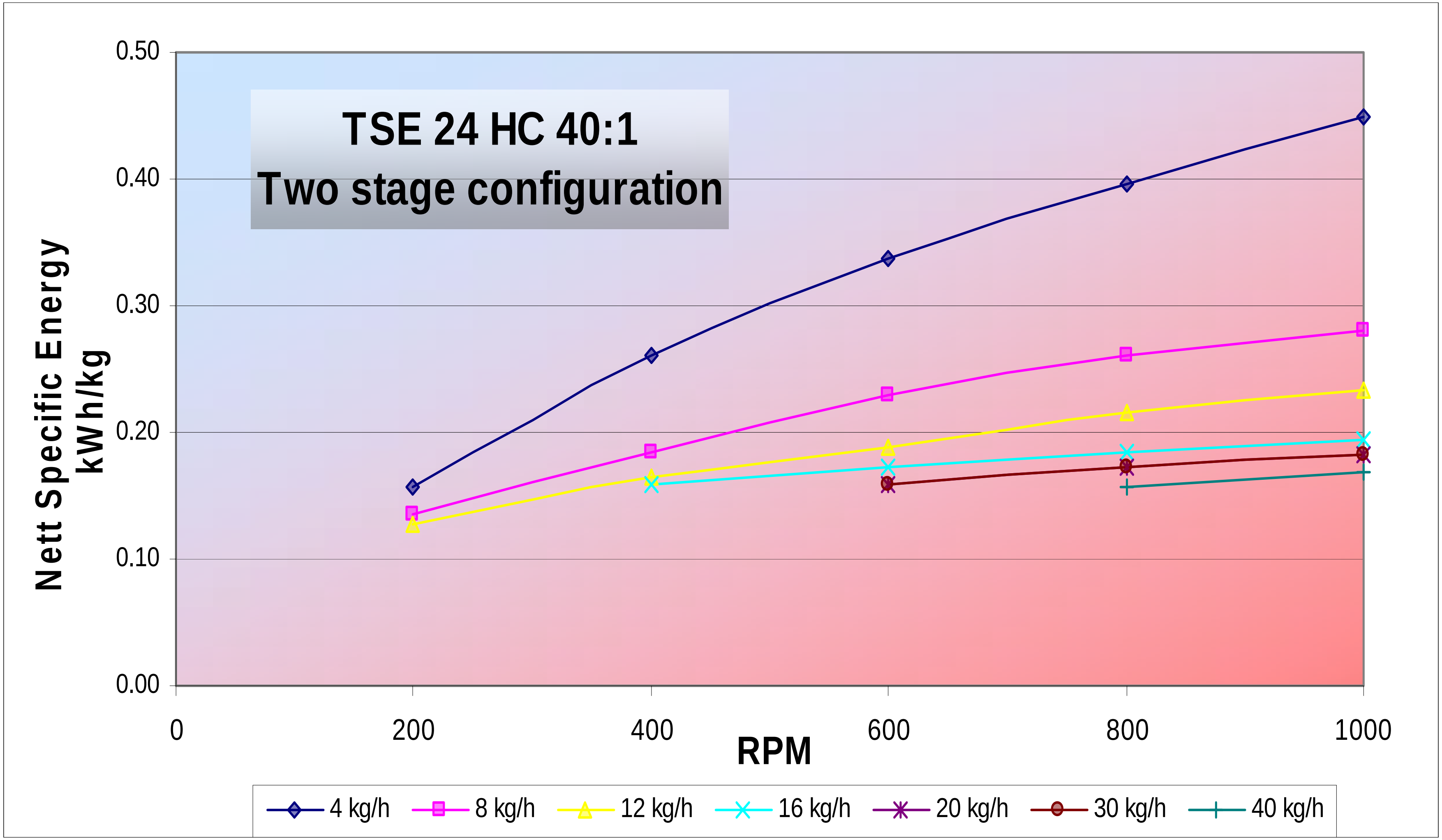
# Specific Energy in a twin-screw



# Specific Energy in a twin-screw



# Effect of Screw Speed



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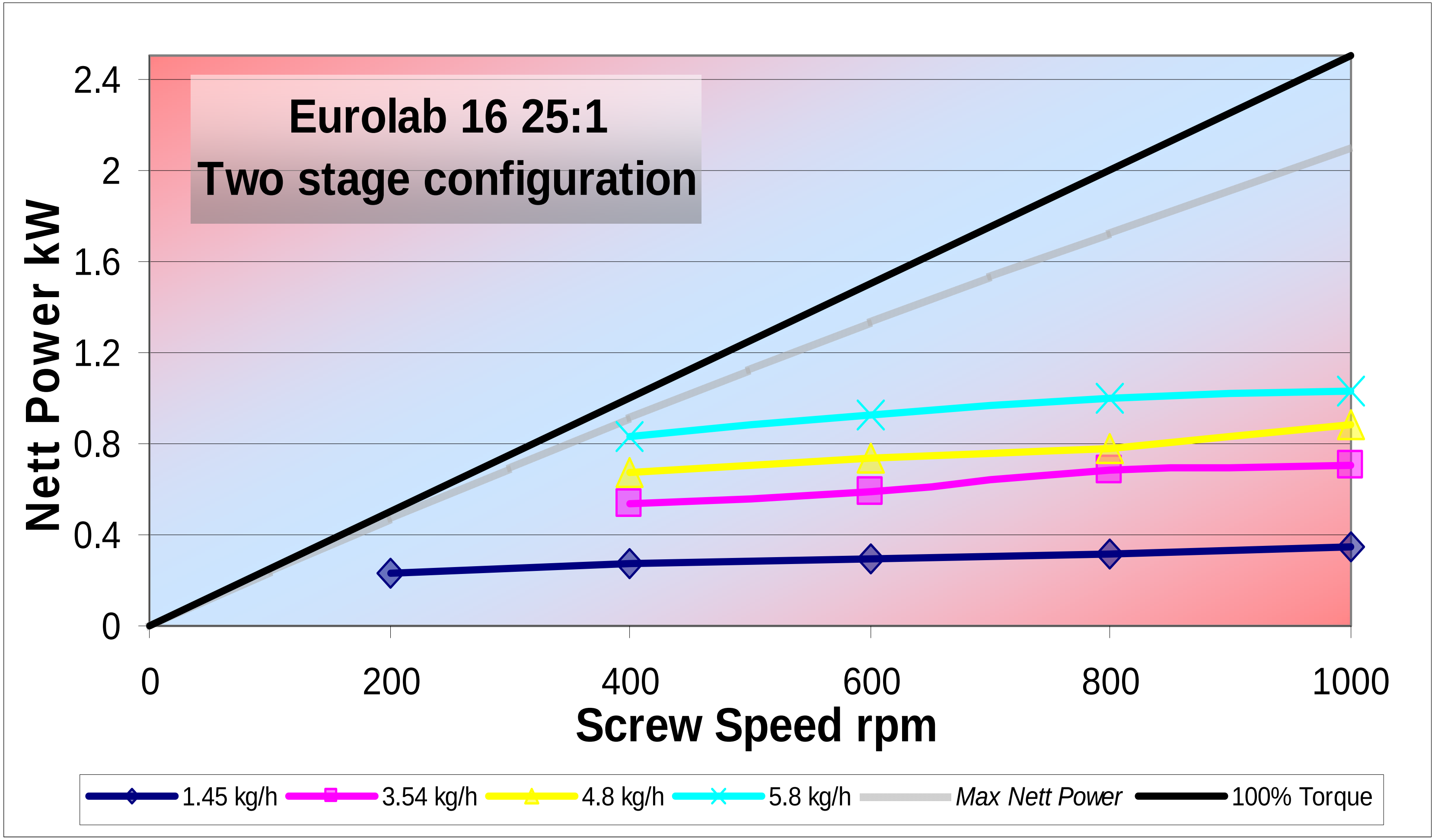
# Power vs.. Screw speed 16mm



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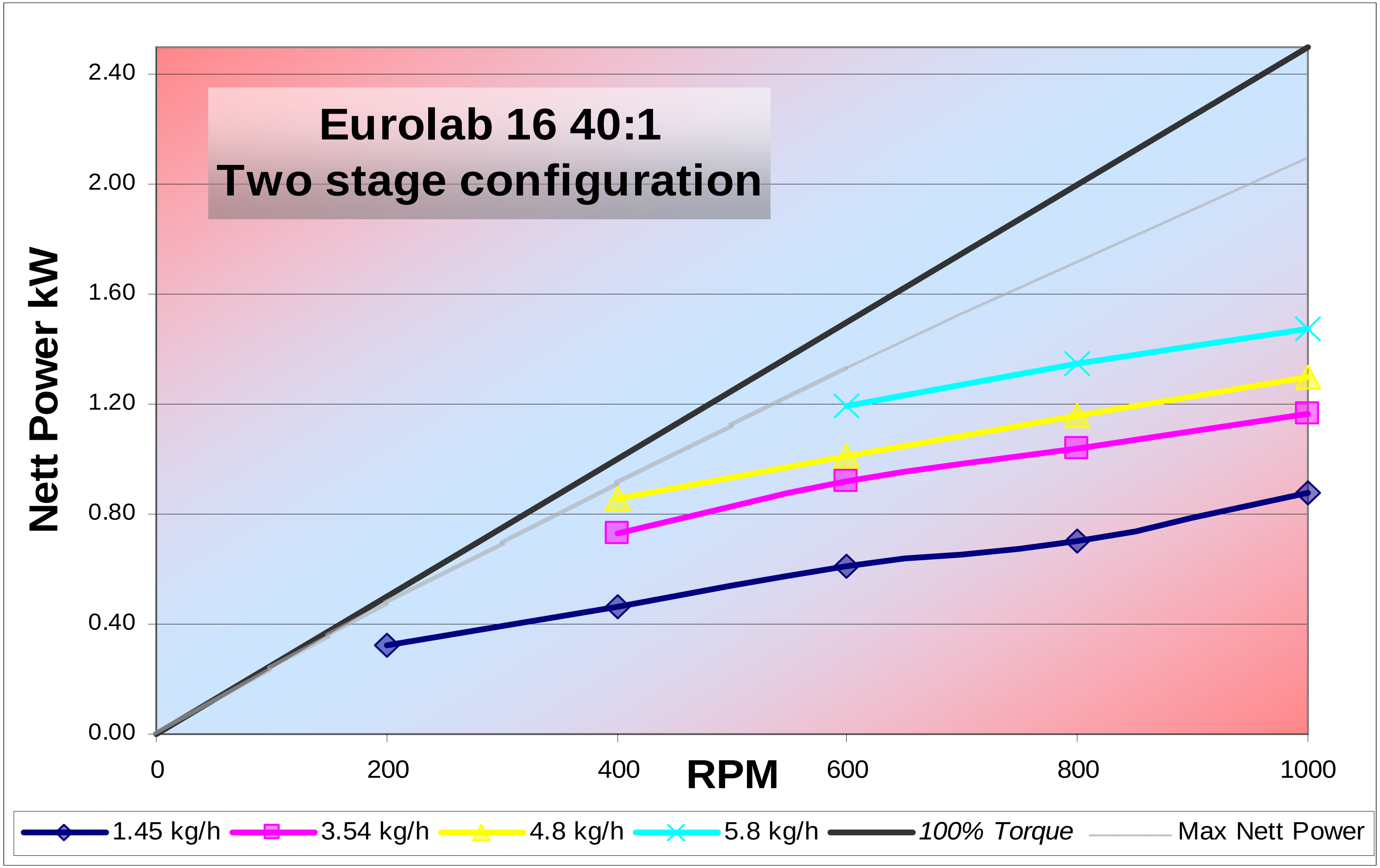
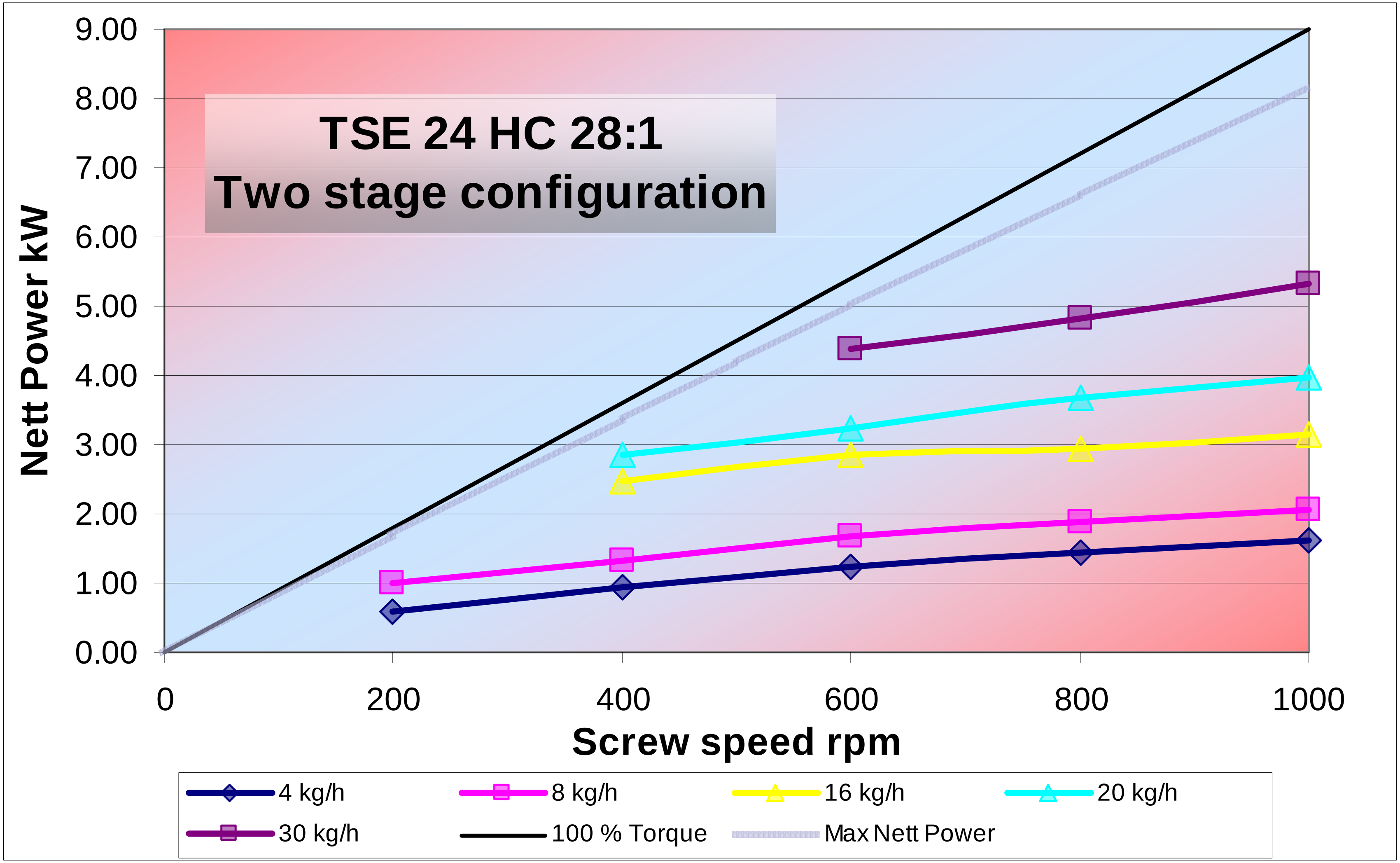
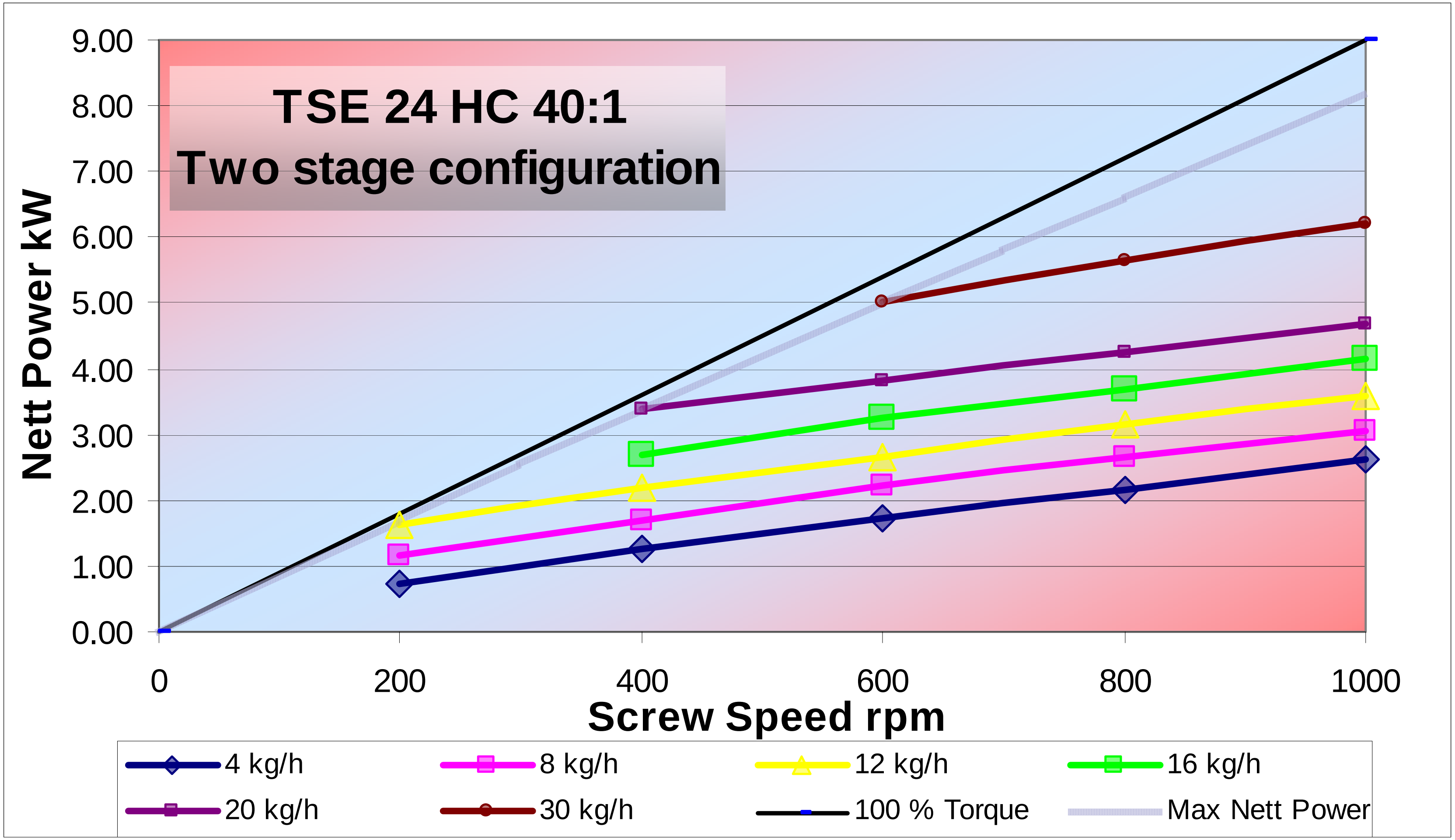


# Power vs. Screw speed 24mm 28:1



# Power vs.. Screw speed 24mm 40:1



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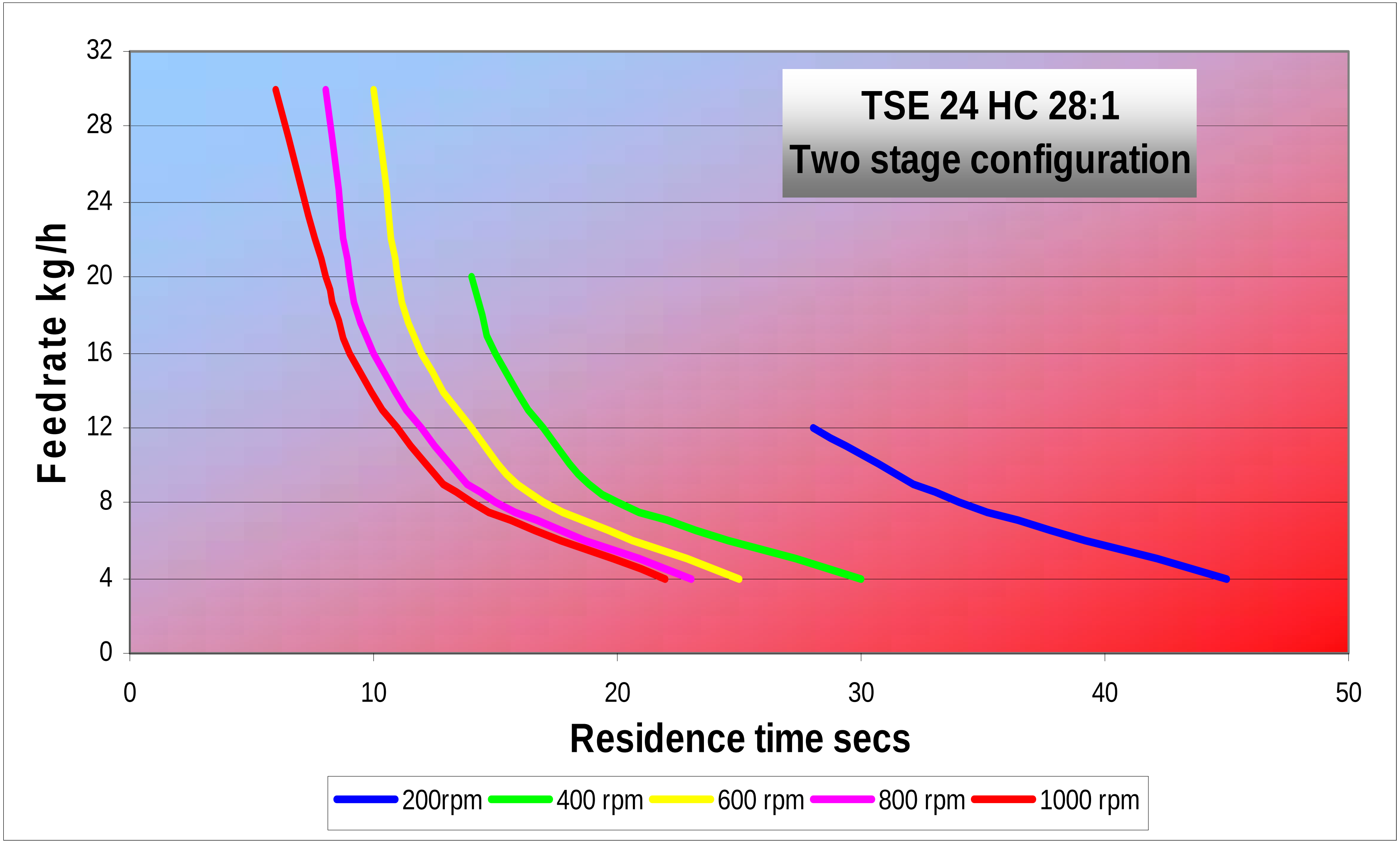
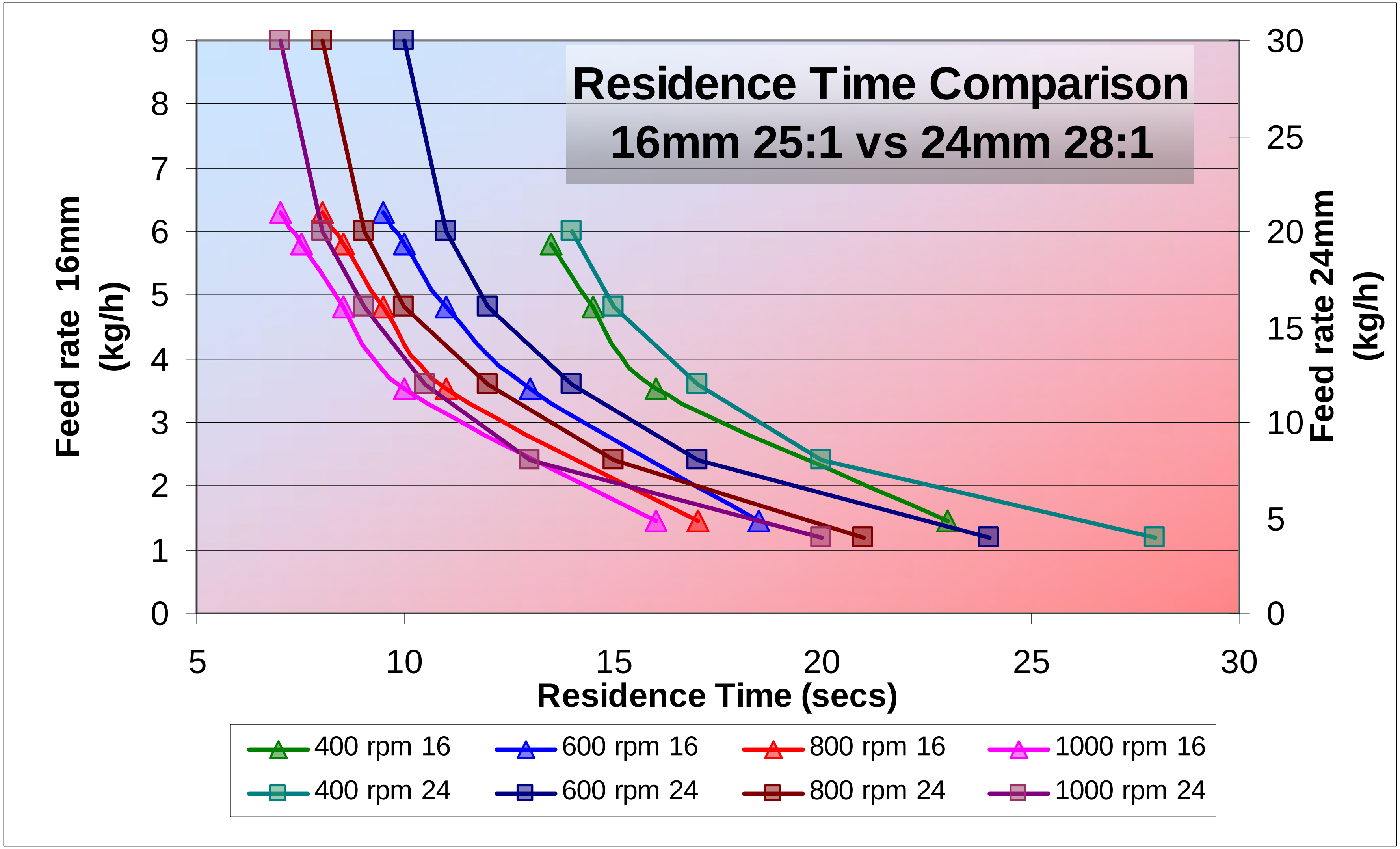
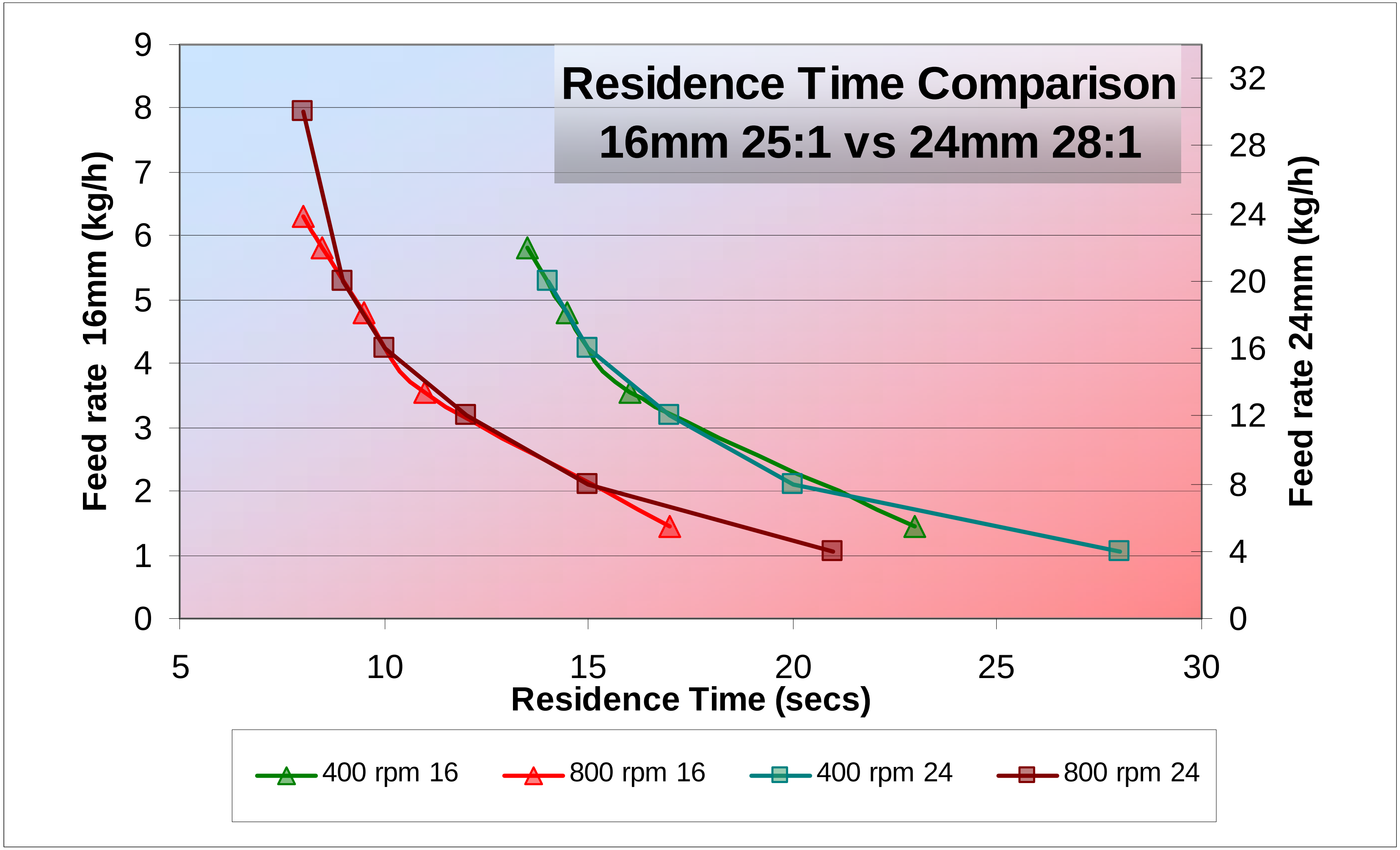
# Residence time in a twin-screw



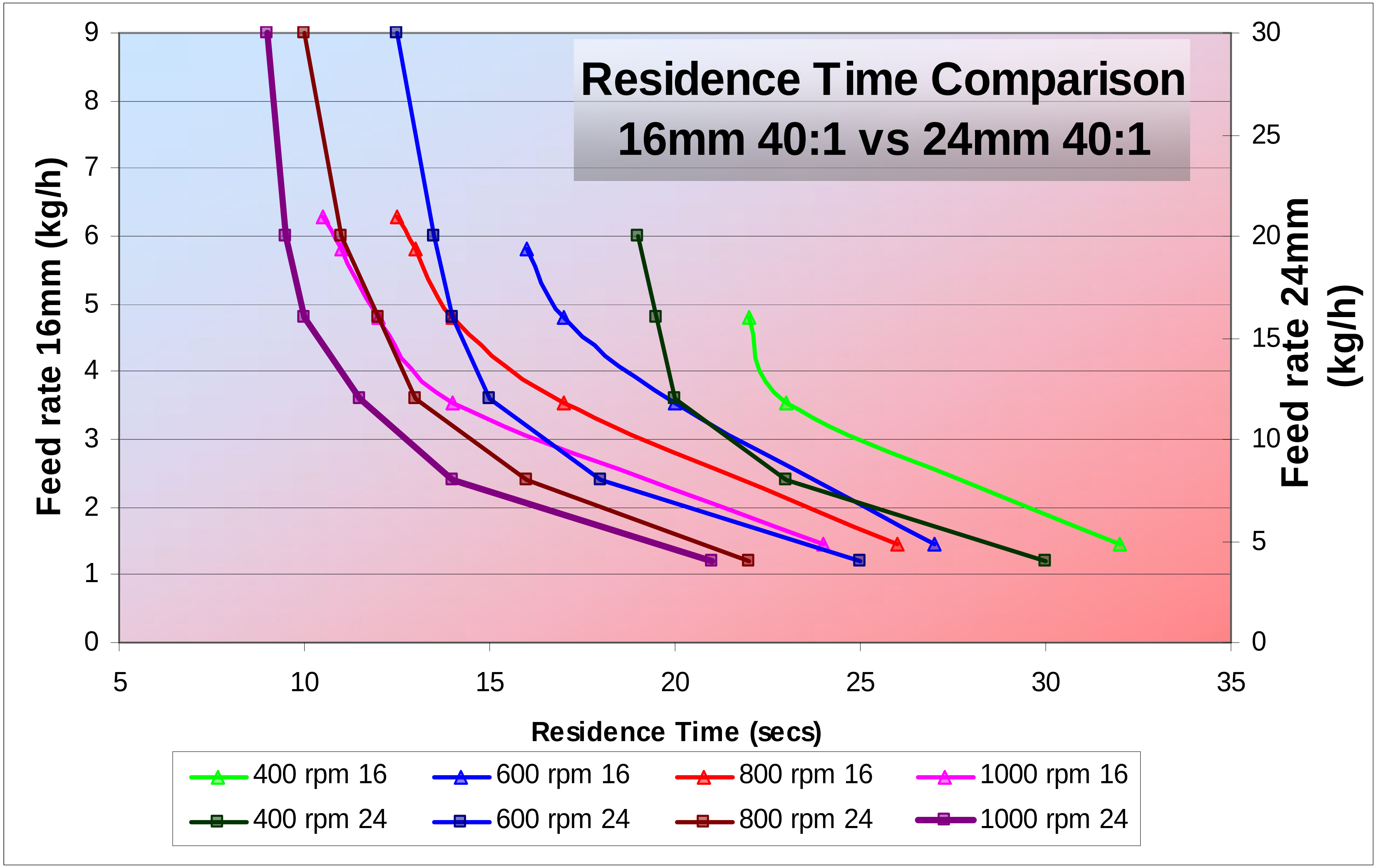
# Residence time in a twin-screw



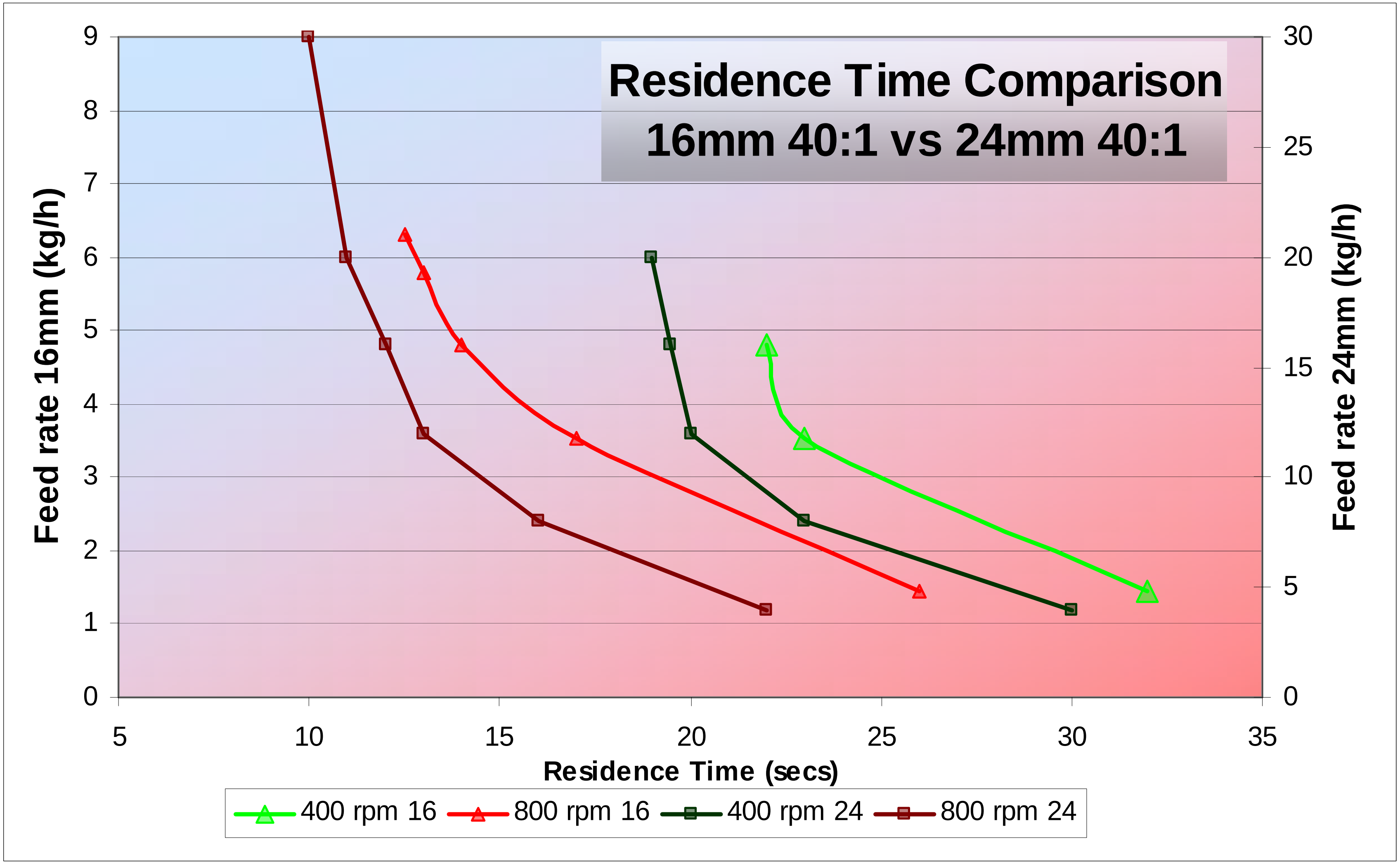
# Residence time in a twin-screw



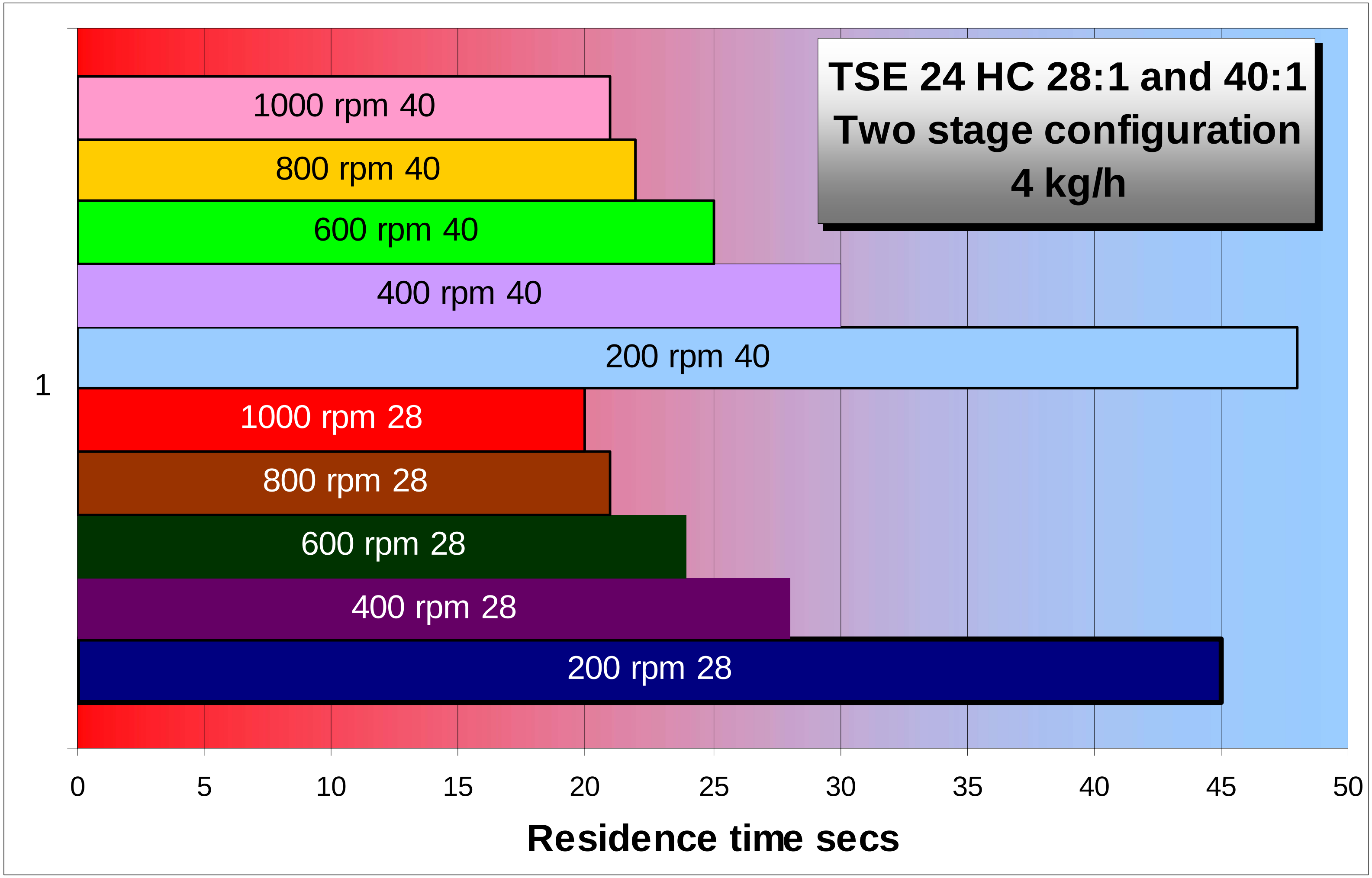
# Residence time in a 40:1 twin-screw



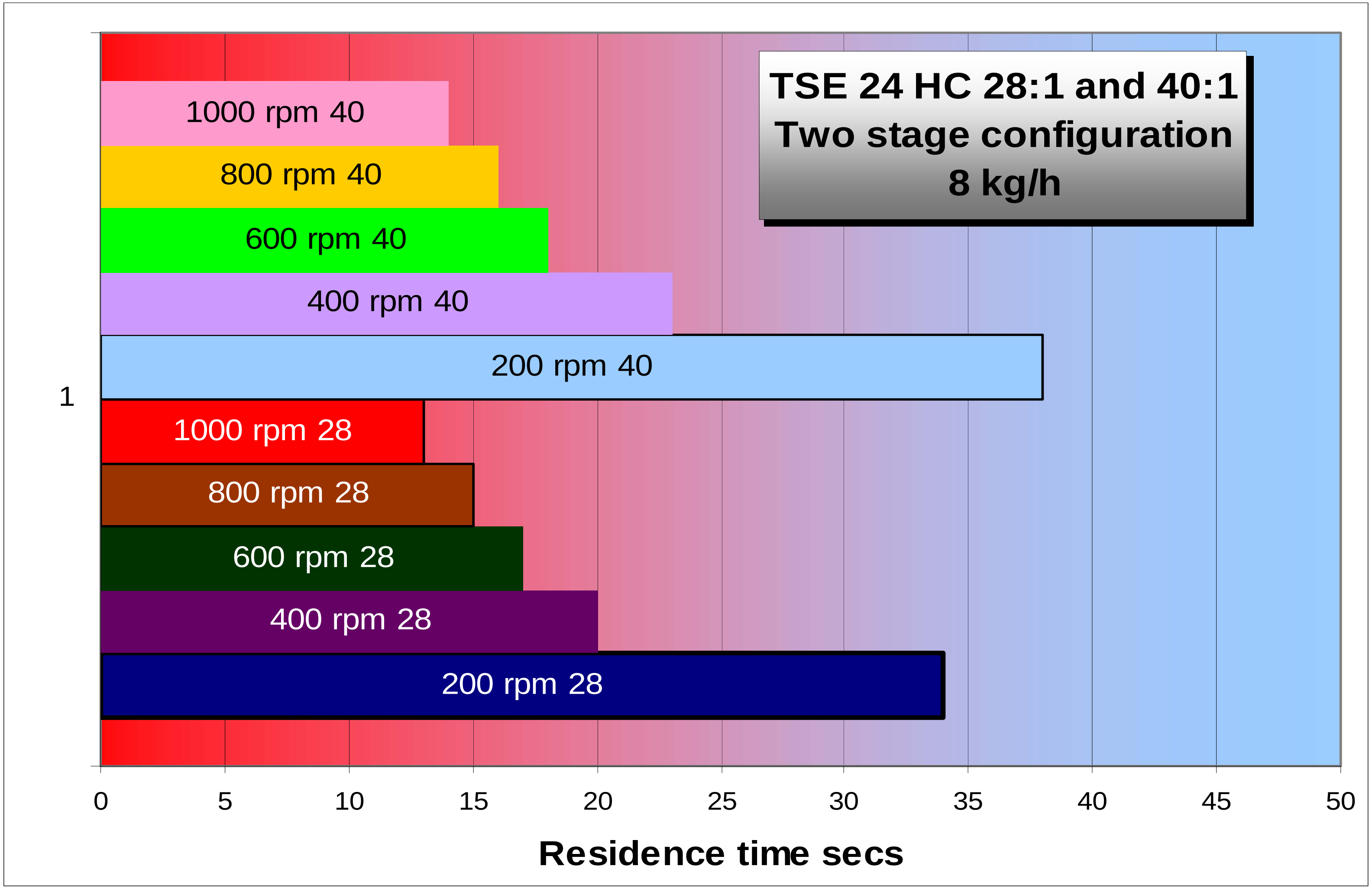
# Residence time in a 40:1 twin-screw



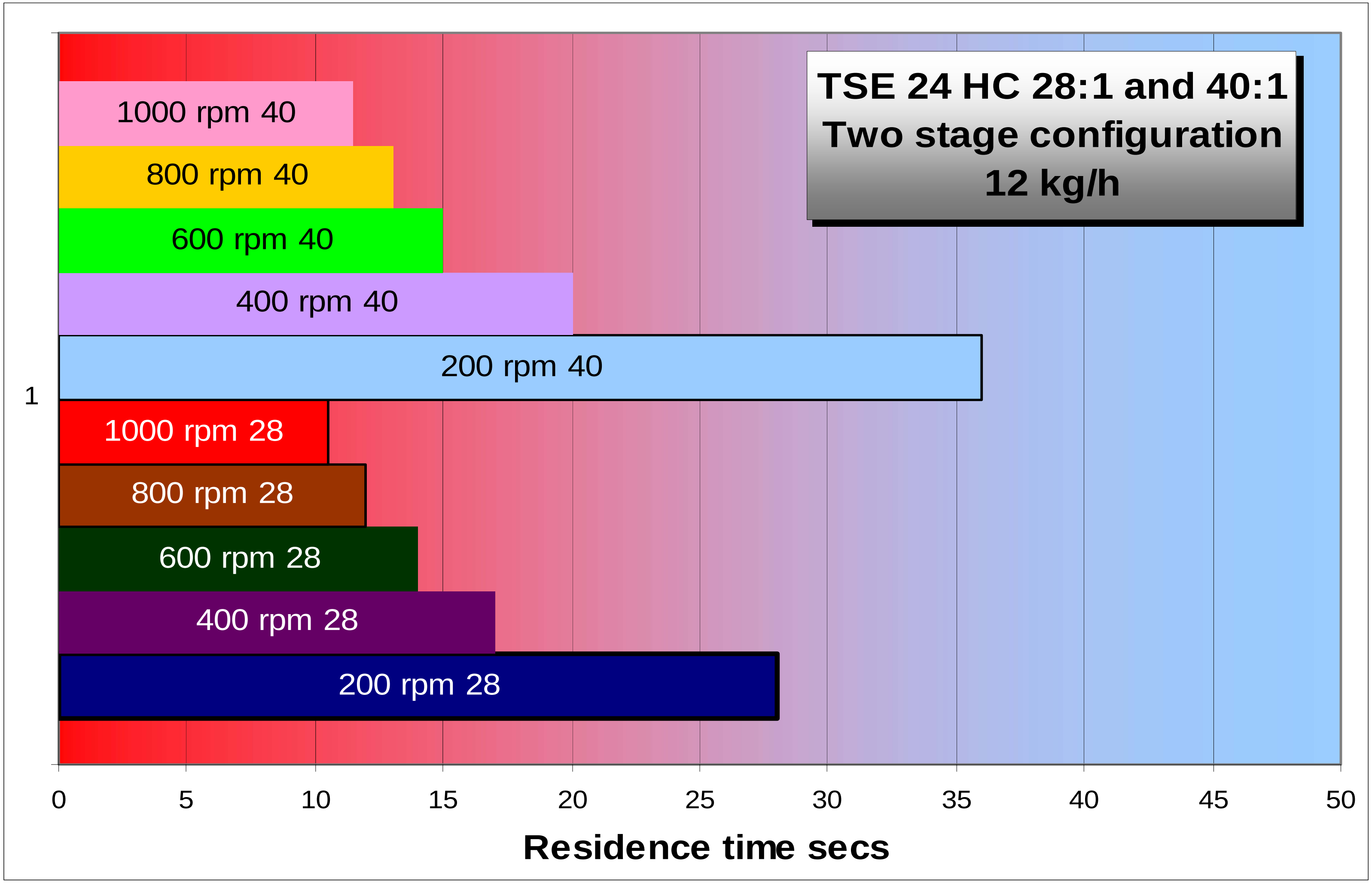
# Effect of Barrel length 4 kg/h



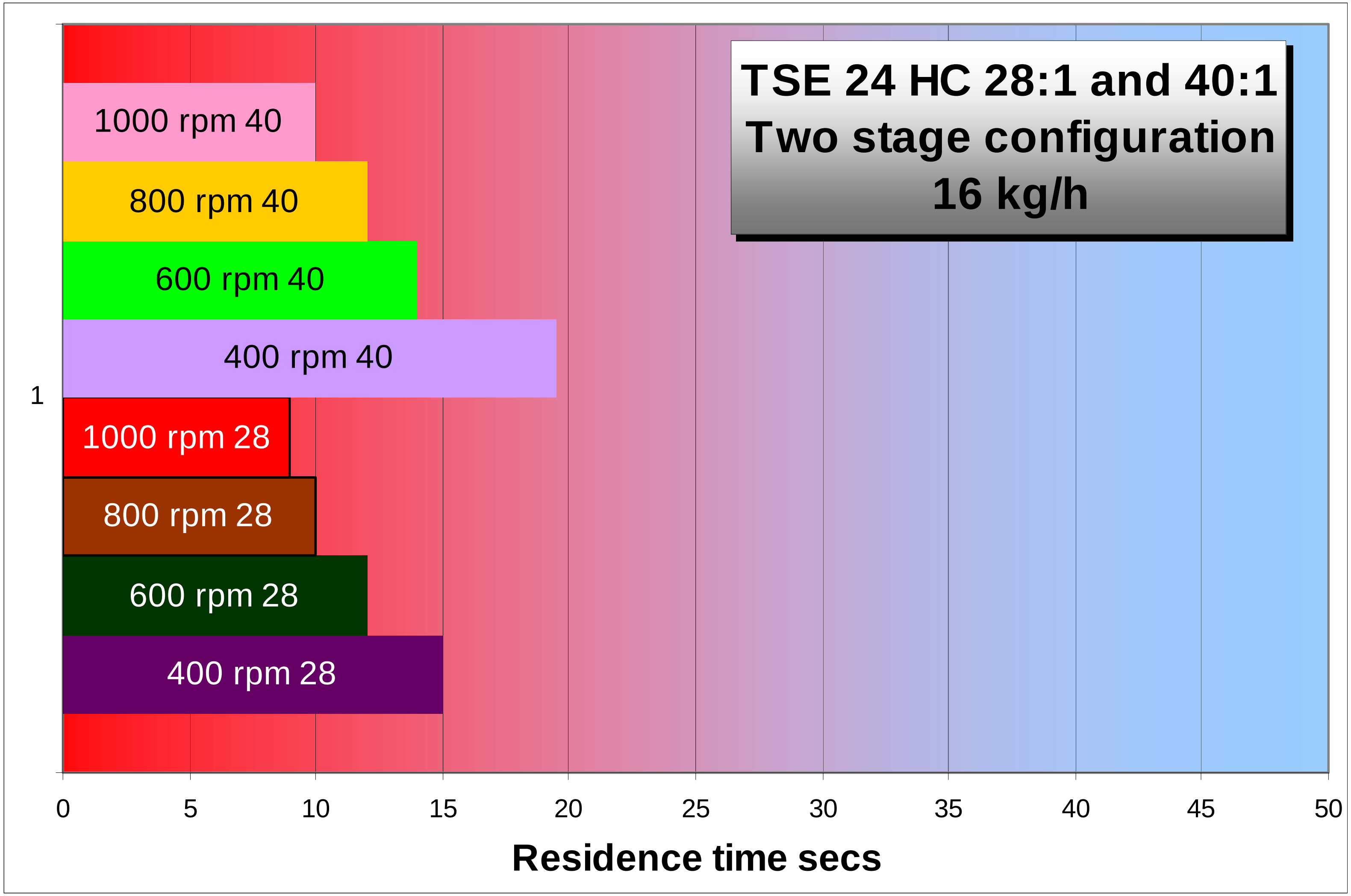
# Effect of Barrel length 8 kg/h



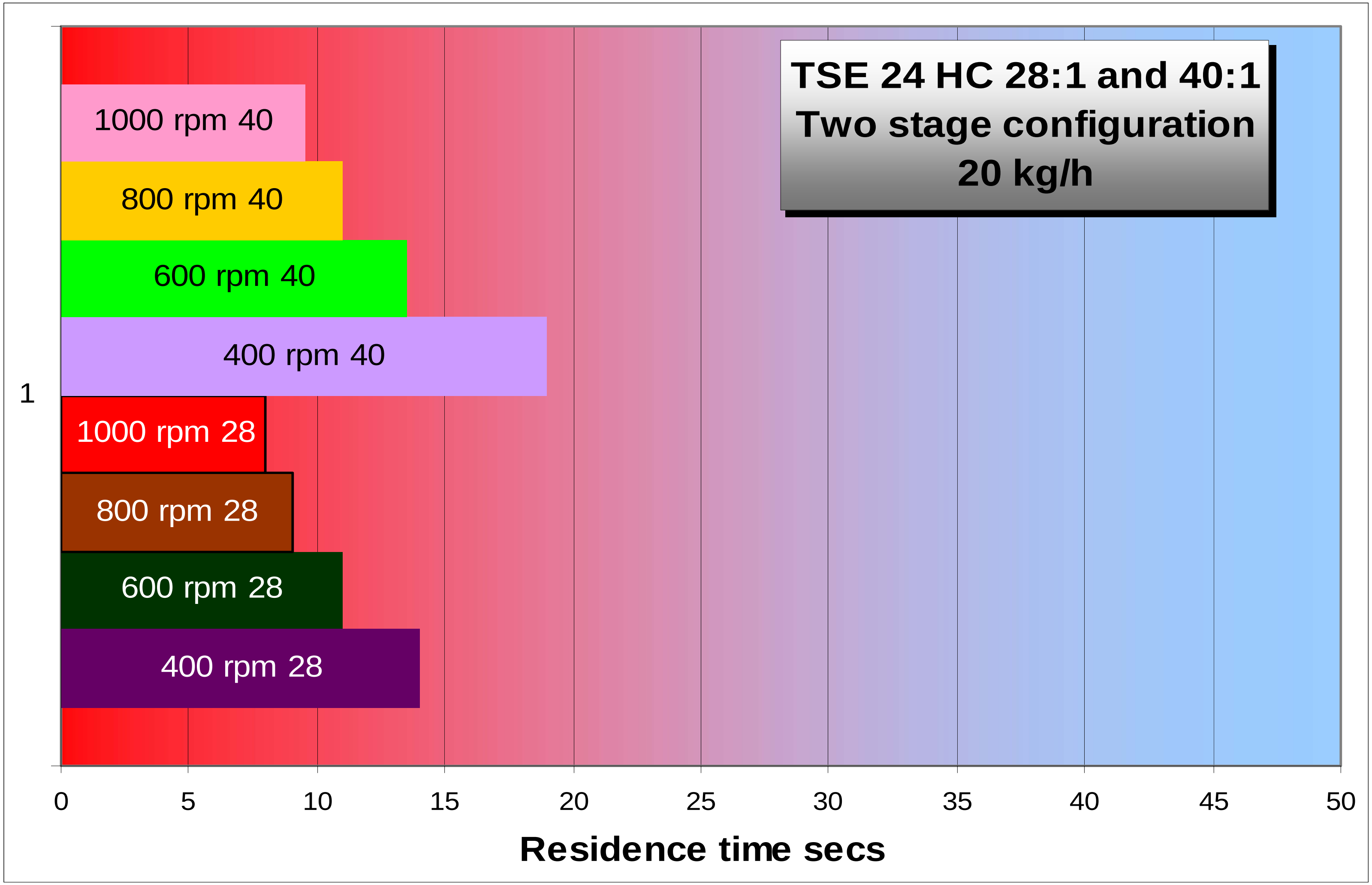
# Effect of Barrel length 12 kg/h



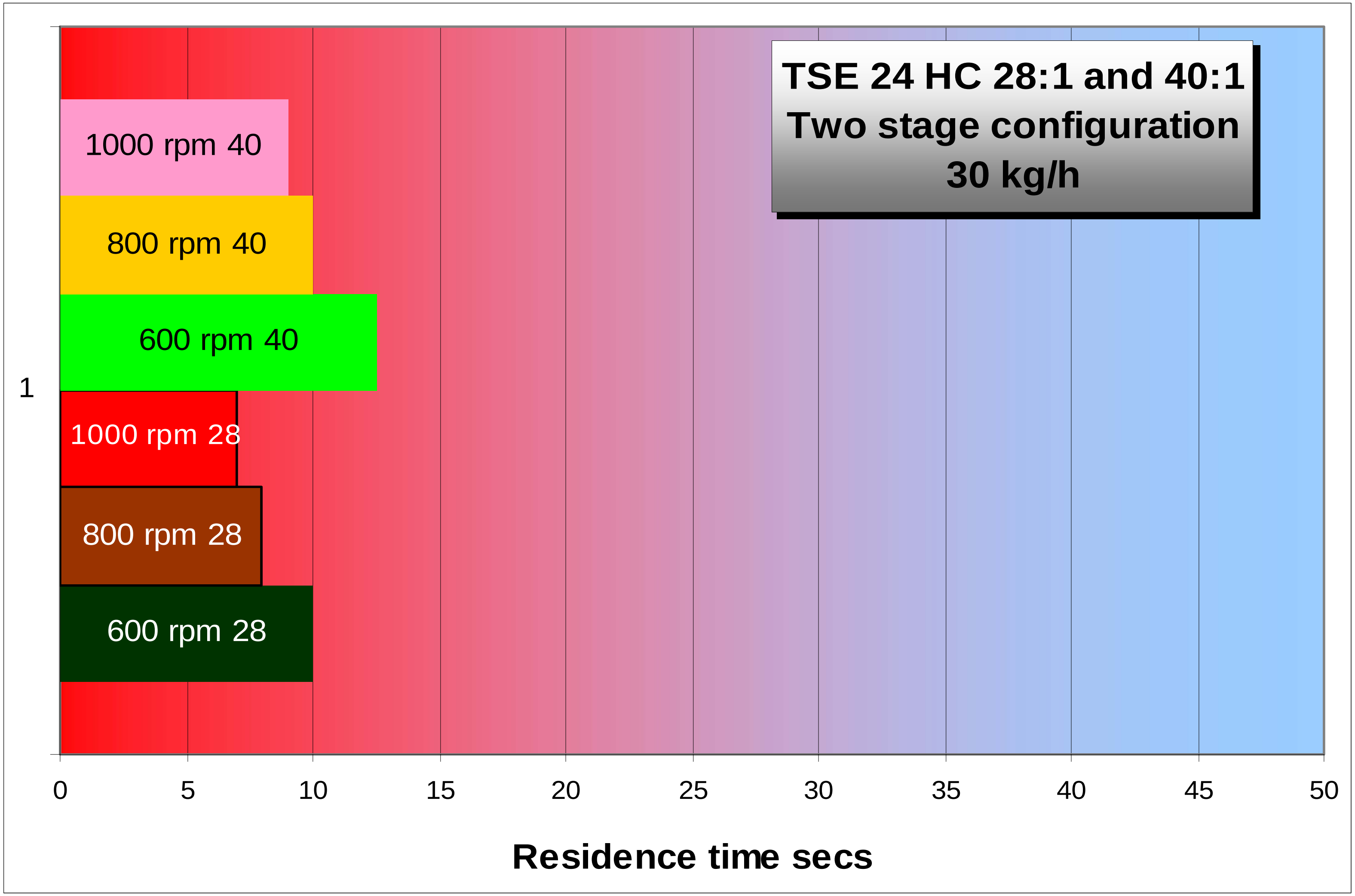
# Effect of Barrel length 16 kg/h



# Effect of Barrel length 20 kg/h



# Effect of Barrel length 30 kg/h



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   - **Degree of Fill**
5. Scale-up and heat transfer

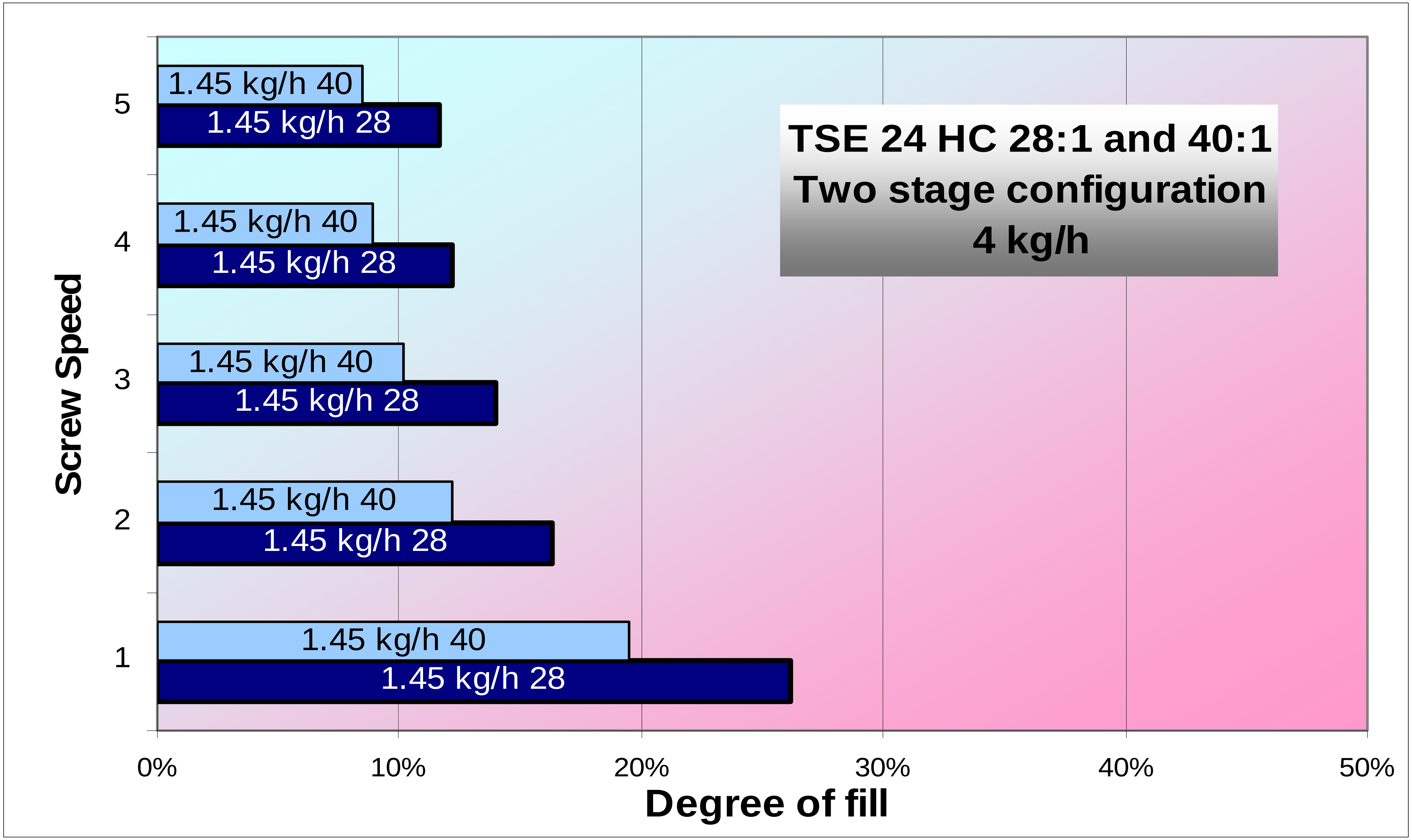
# Degree of Fill

It is possible to calculate the degree of fill in the barrel, from knowledge of the extruder free volume, residence time, feed rate and melt density of the product.

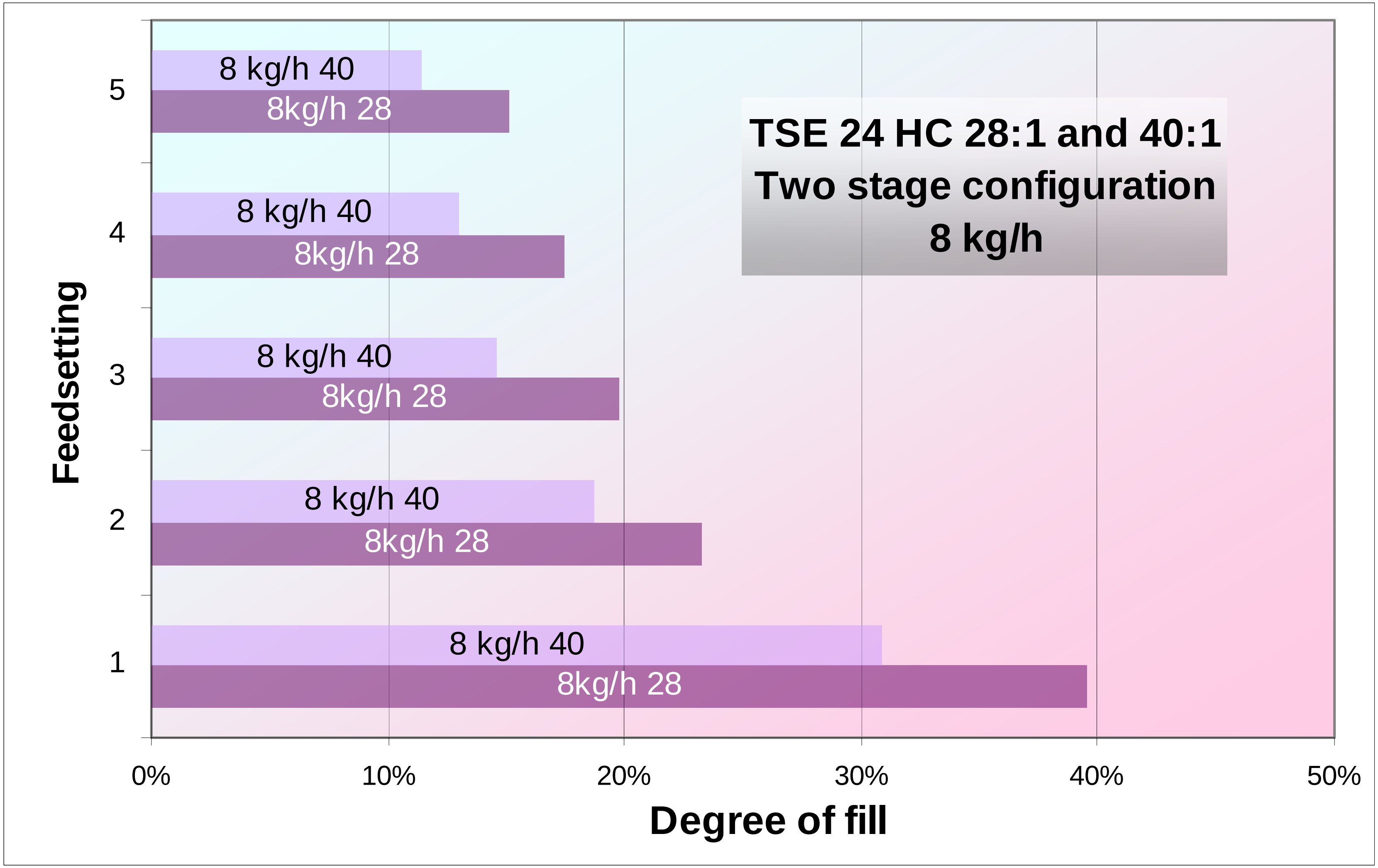
| | | |
|---|---|---|
| **F**eed rate in grammes/minute | = | **F** |
| Residence **T**ime in minutes | = | **T** |
| Product **D**ensity in grammes/ml | = | **D** |
| Extruder free **V**olume in ml | = | **V** |

$$\textbf{Degree of fill in \%} = \frac{\mathbf{F \times T}}{\mathbf{D \times V}}\ \mathbf{\%}$$

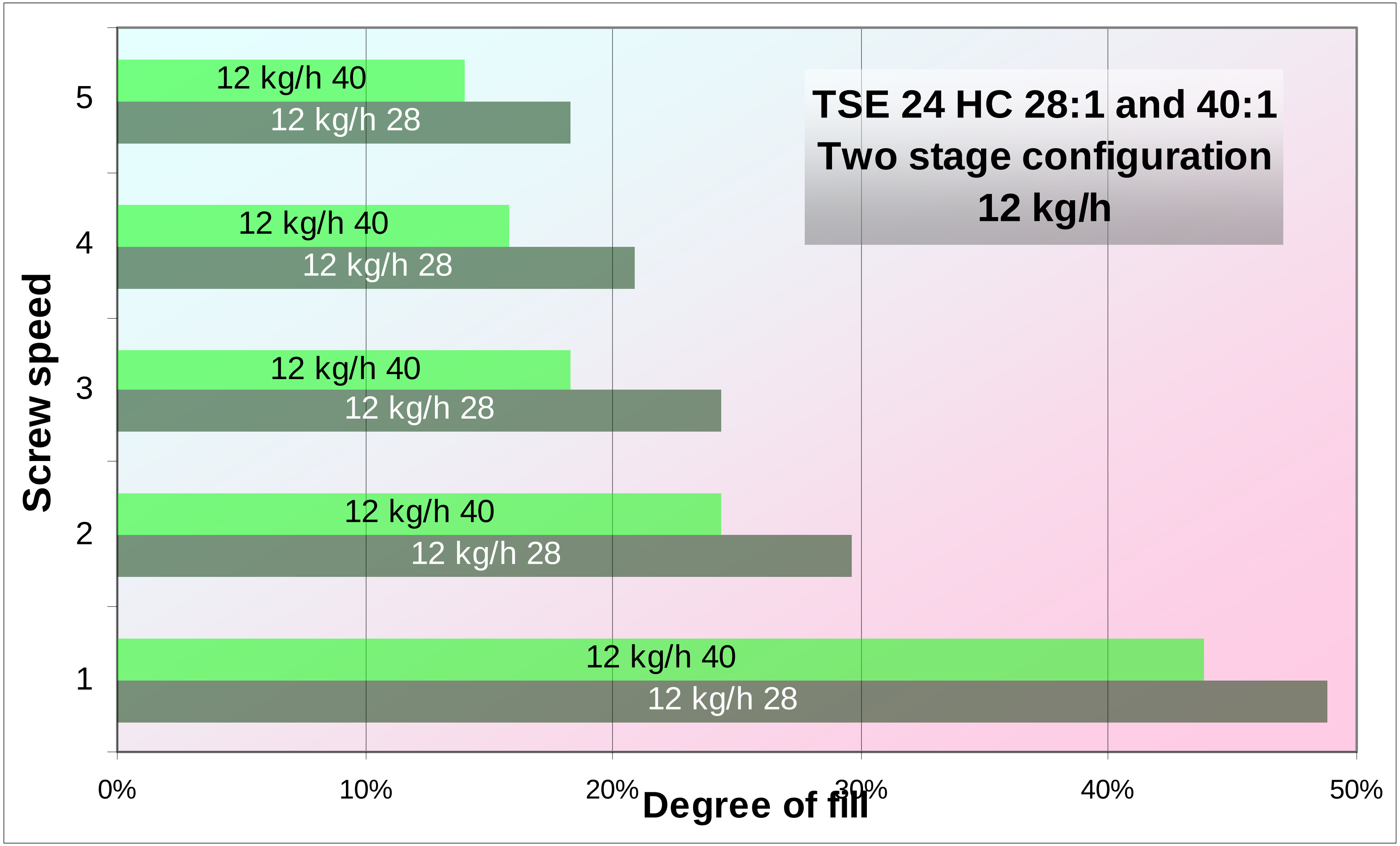
# Effect of Barrel length 4 kg/h



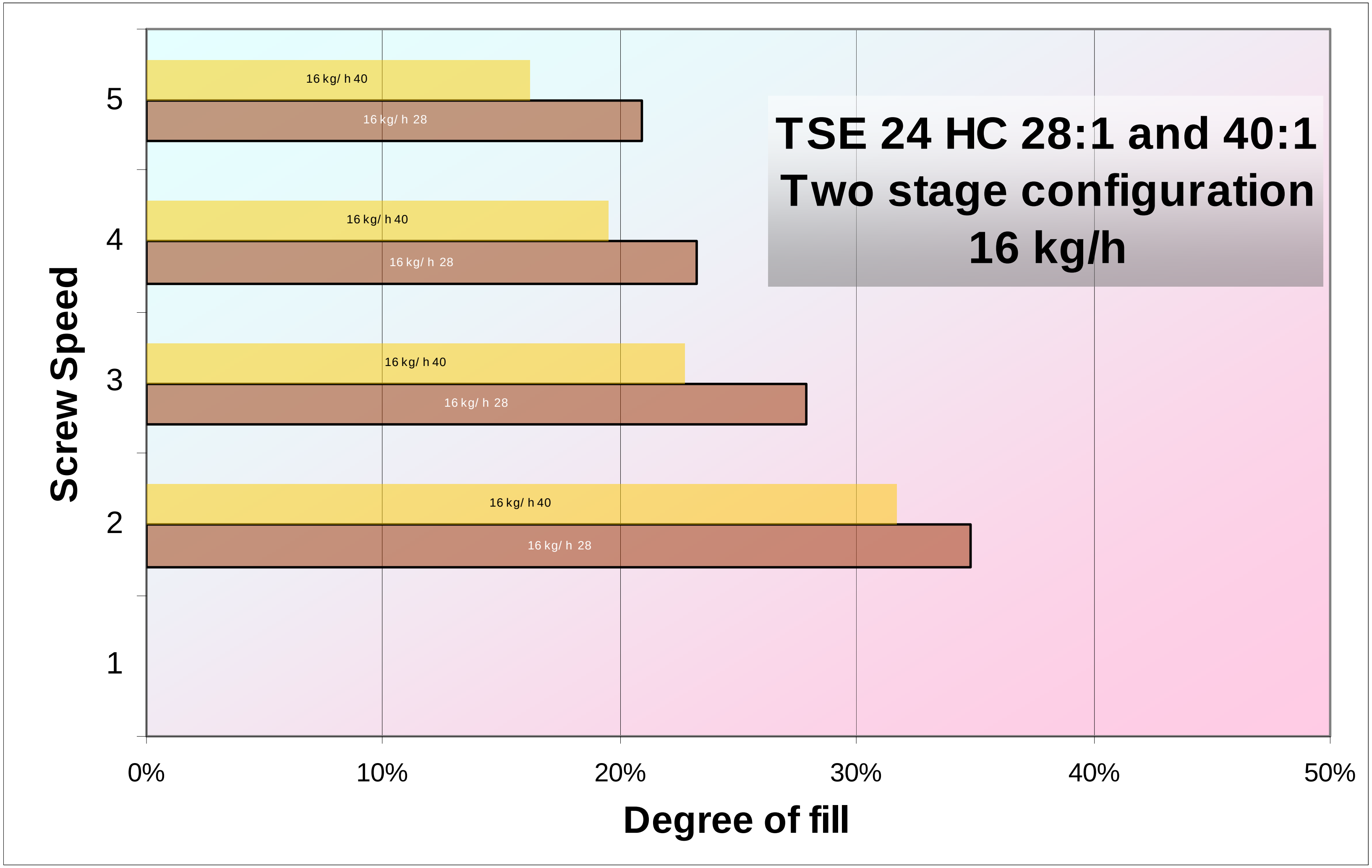
# Effect of Barrel length 8 kg/h



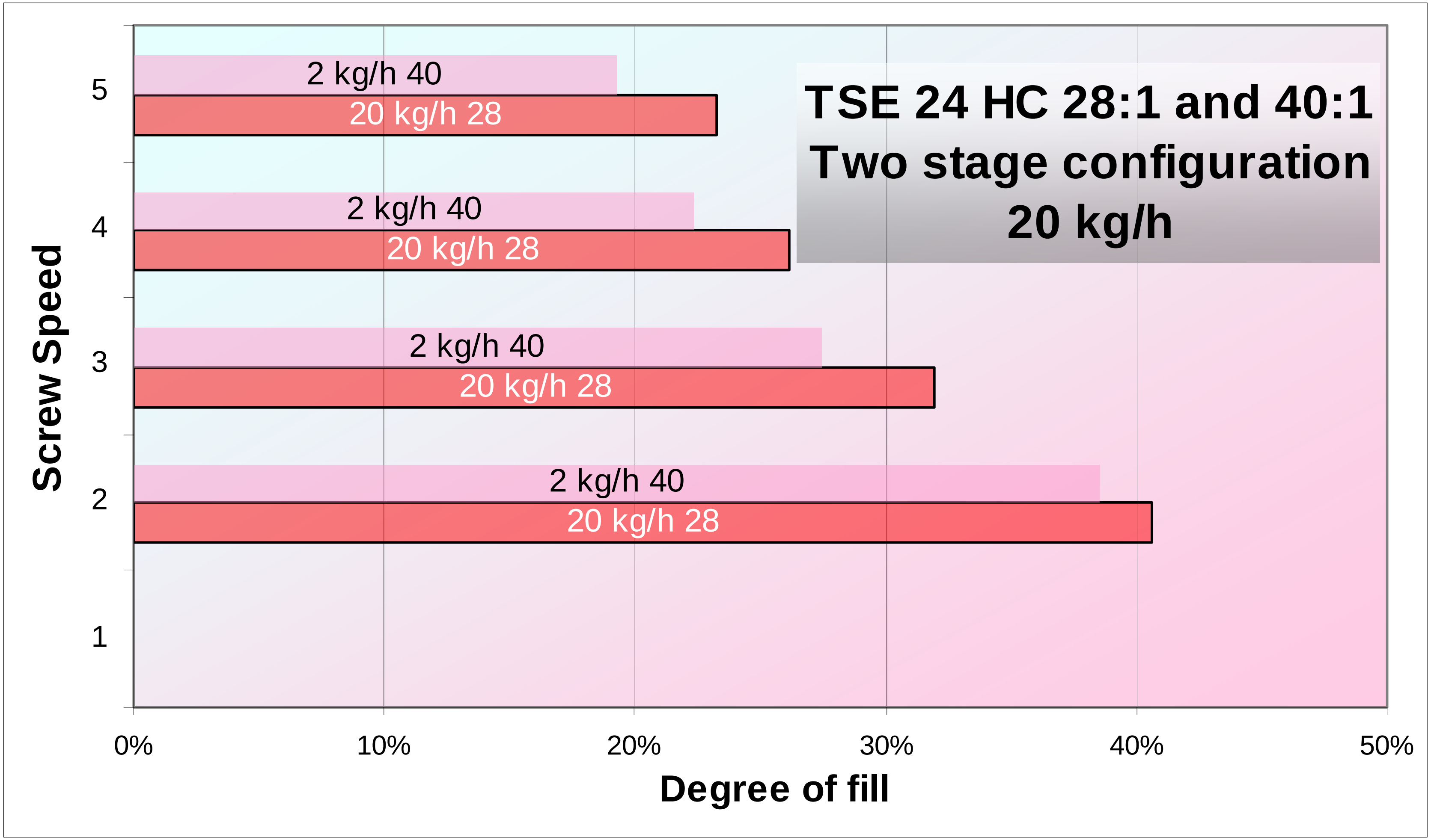
# Effect of Barrel length 12 kg/h



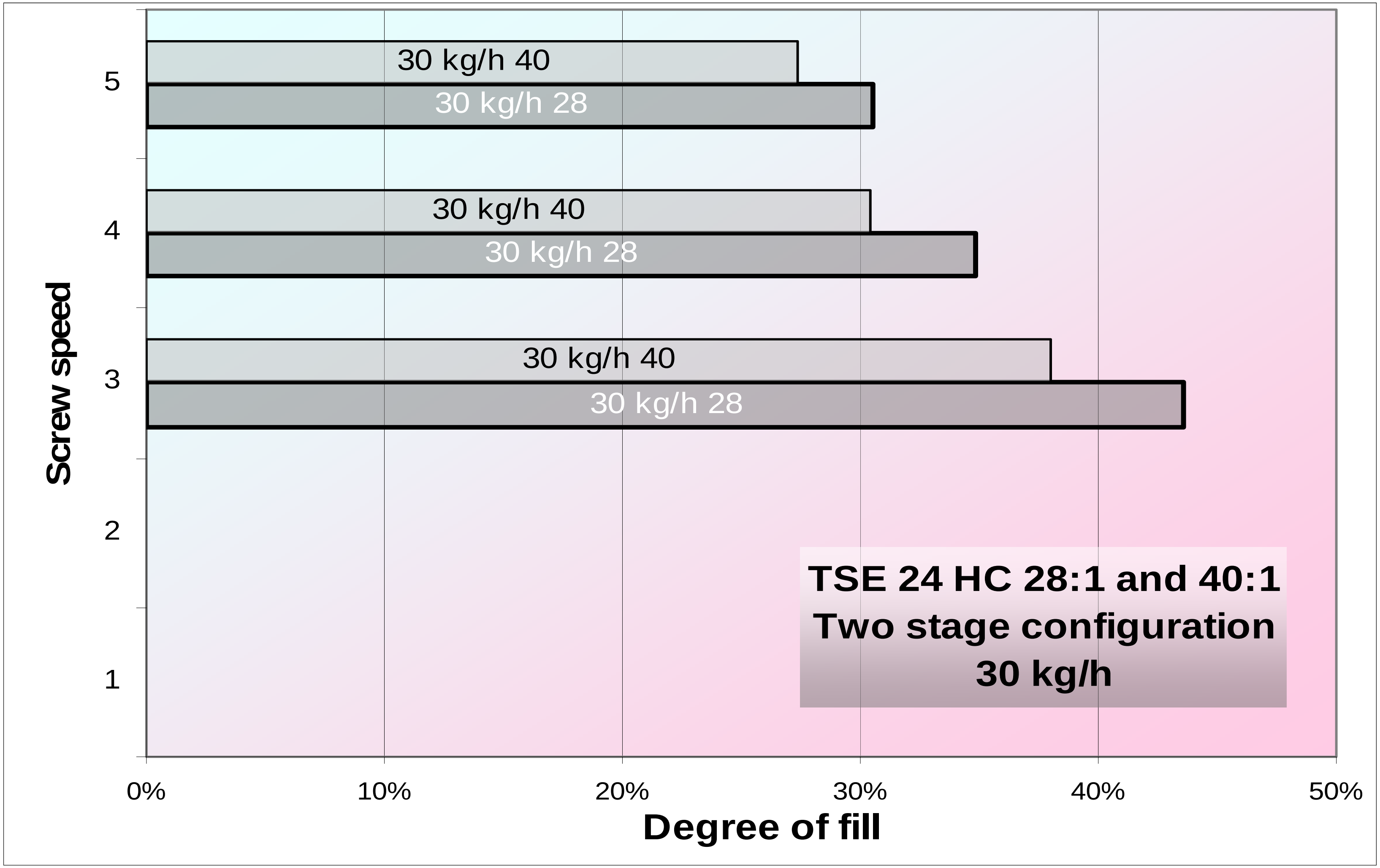
# Effect of Barrel length 16 kg/h



# Effect of Barrel length 20 kg/h



# Effect of Barrel length 30 kg/h



# Scale-up

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   - Degree of Fill

## 5. Scale-up and heat transfer

# Process Scale-up

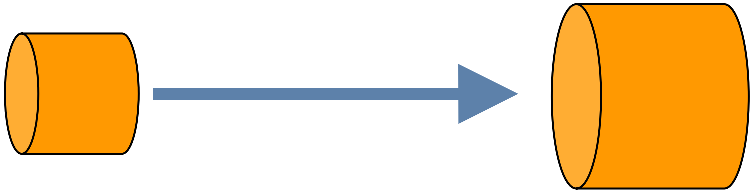
16mm
Laboratory extruder
5 kg/h


48mm Production extruder
150 kg/h

# Surface Areas and Volumes

D = 16mm

D = 24mm



L = D = 16mm (1)

L = D = 24mm (1.5)

| | | D = 16mm | D = 24mm |
|---|---|---|---|
| Surface area | $= \pi D^2$ | 256 mm² (1) | 576 mm² (2.25) |
| Volume | $= \frac{1}{4} \pi D^2 L$ | 1,024mm³ (1) | 3,456mm³ (3.375) |
| Area/ Volume | $= 1/D$ | 0.0625 mm⁻¹ (1.5) | 0.04167 mm⁻¹ (1) |

# Adiabatic Operation

1. **Set extruder barrel temperatures to match melting point of polymers to be processed.**
2. **Begin extrusion, and monitor temperatures within the extruder, or at the discharge.**
3. **Align barrel temperatures to match the measured melt temperatures.**
4. **If temperature level exceeds desired limits, modify process conditions of screw speed and feed rate.**
5. **If temperatures are still outside the limits, consider changes to the screw configuration.**

# Summary

1. Twin screw melting and Mixing Process

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3. Use of Specific Energy Input to predict performance

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# Ancillary Equipment

# Conclusions

1. **Measuring Specific Energy Input on a laboratory scale extruder allows prediction of performance of a production extruder, operating under similar conditions of screw speed and residence time.**

2. **At a fixed feed-rate, increasing screw speed will <u>increase</u> product specific energy and temperature, because of increased shear rate.**

3. **At a fixed screw speed, increasing feed-rate will <u>reduce</u> product specific energy and temperature, because of reduced residence time.**

4. **Increasing the L/D of an extruder will <u>increase</u> specific energy input, and residence time, even if the extra length is only conveying screws.**

5. **Operating a twin screw extruder adiabatically will avoid scale-up problems from differences in heat transfer**

# Acknowledgements

**Wells Plastics in Stone for donation of the polymer used in the experiments**

**Jim McLatchie for assistance in collecting the data during the tests**

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