Water Bath Length Determination - A Theoretical Approach

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Past Work and Attributions

This question has been explored in the past by experts like Jim Frankland and Leonard Sansone.

This presentation’s purpose is to walk through an example using a hybrid of these methods for a strand pelletizing operation.
In designing a plastic pelletizing operation using strand pelletizers, determining how long the water bath should be is probably one of the more overlooked aspects in process design. The length of the water bath usually ends up being decided not by a theoretical approach or practical experience, but by how much space is left over on the production floor.
Background

Most processors have a water bath that only allows for some of the plastic strand to cool, namely the outer shell, while the inside remains molten. You can observe this in most operations as the strand going into the pelletizer is often cool enough to touch while after the pelletizer, that heat inside the strand is released as pellets are cut and the batch of pellets are hot to the touch.

This kind of heat transfer is unsteady state heat transfer as the entire strand is not allowed enough time to sit in the water bath for the entire strand to reach an equilibrium temperature with that of the bath.
Background (Cont’d).
When a plastic strand enters the water bath, the strand heats up the water around it or forms a steam jacket and so your cooling water is trying to cool that hot water layer before it can cool the strand. This delays the full cooling effect of the water bath. In the absence of any turbulence, you’re basically left with trying to cool hot plastic strands with warm water leaving you with a suboptimal cooling situation.

©Conair – used with permission.
Background (Cont’d).

When the cool water does reach the polymer, one has to remember that polymers are very poor thermal conductors by nature, so they don’t transfer heat very well even under good circumstances. This suboptimal cooling along with the very short residence time that strands stay in the water bath and poor thermal conductivity leaves you with a temperature profile of a cool exterior and a hot (if not molten) interior.
Drawbacks of theoretical method

Keep in mind, this method isn’t perfect as this method ignores the effects of:

• Number of strands
• If the polymer is **crystalline**, the polymer’s heat of fusion as it goes from molten to solid
• The changing values of constants (i.e. **heat capacity of polymer**) as temperature changes
• Number of times strands leave and re-enter water bath
• Additives or fillers and their effects on physical properties
Sources

All values and equations can be found via internet searches, websites such as The Engineer’s Toolbox, or textbooks found on Scribd. The specific sources can be found in the appendix.
Assumptions

I’ll assume a width of the water bath of 2 ft. to fit all the strands coming out of the die and a water depth of 1 ft. in order to try to keep the flow of water as turbulent as possible.

This is in order to promote heat transfer by keeping the cross-sectional area of the water bath as small as possible.
Information you need before you start – die head

The first step is to calculate your production’s estimated line speed so you’ll need data about your proposed die head.

<table>
<thead>
<tr>
<th>Die Hole Diameter ($D_{Die}$)</th>
<th>0.188 in=0.01567 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Die Holes ($N_{Die}$)</td>
<td>71</td>
</tr>
<tr>
<td>Production Rate</td>
<td>7,000 lbs/hr</td>
</tr>
<tr>
<td>Production Rate Per Hole ($m_{Die Hole}$)</td>
<td>98.59 lbs/hr</td>
</tr>
<tr>
<td>Density of Polypropylene ($\rho_{PP}$)</td>
<td>56.809 lbs/ft$^3$</td>
</tr>
</tbody>
</table>

Line speed equation

$$Line \ Speed \ (fps) = \frac{(m_{Die \ Hole}/\rho_{PP})}{\pi \times \left( \frac{D_{Die}}{2} \right)^2} \times \frac{1 \ hour}{3600 \ seconds}$$

$$Line \ Speed = 2.500 \ \frac{ft}{s}$$

Extrusion, the definitive processing guide and handbook by Giles Jr., p. 46
Steps to solve

Next, the following calculations will be performed in order to attain the estimated water bath length.

- Calculate the hydraulic diameter ($d_h$) of the water bath
- Calculate the Reynolds number ($Re$) for water
- Calculate Prandt number ($Pr$) for the water
- Calculate the Nusselt number ($Nu$)
- Calculate the convective heat transfer coefficient ($h$)
- Use the Heisler Chart to find Fourier number ($Fo$)
- Calculate water bath length ($L_{water\ bath}$)
Step 1 – Calculate hydraulic diameter

Calculate the hydraulic diameter ($d_h$) of the water bath

- $a = \text{width of water bath} = 2 \text{ ft}.$
- $b = \text{depth of water bath} = 1 \text{ ft}.$
- $d_h = \frac{2 \times a \times b}{a + b}$
- $d_h = \frac{2 \times 2 \text{ ft} \times 1 \text{ ft}}{2 \text{ ft} + 1 \text{ ft}} = 1.333 \text{ ft.} = 0.4064 \text{ m}$
Step 2 – Calculate Reynolds Number for water

- $d_h = \text{hydraulic diameter} = 0.4064 \, m$
- $\nu_{f, 78^oF} = \text{kinematic viscosity of water} = 8.87 \times 10^{-2} \frac{m^2}{s}$
- $A = \text{cross-sectional area of water bath} = 2 \, ft. \times 1 \, ft = 2 \, ft^2 = 0.186 \, m^2$
- $Q_{\text{water}} = 21 \, gpm = 1.325 \times 10^{-3} \frac{m^3}{s}$
- $Re = \frac{Q \times d_h}{\nu \times A} = \frac{0.001325 \frac{m^3}{s} \times 0.4064 \, m}{8.87 \times 10^{-2} \frac{m^2}{s} \times 0.185806 \, m^2}$
- $Re = 3267.02$

Streamlines In Laminar, Transition, and Turbulent Flow Regimes In Pipe Flow:
Step 3 – Calculate Prandtl Number for water

- \( c_p(f) = \text{Specific heat of fluid} = 4,186 \frac{J}{kg*K} \)
- \( \mu_{f,78^\circ F} = \text{dynamic viscosity of fluid} = 8.78 \times 10^{-4} \text{ Pa s} \)
- \( k_f = \text{thermal conductivity of fluid} = 0.606 \frac{W}{m*K} \)
- \( Pr = \frac{c_p(f) \cdot \mu_{f,78^\circ F}}{k_f} = \frac{4,186 \cdot \frac{J}{kg*K} \cdot 8.78 \times 10^{-4} \text{ Pa s}}{0.606 \frac{W}{m*K}} \)
- \( Pr = 6.06 \)
Step 4 – Calculate Nusselt Number

- Your Nusselt number calculation will be different based on the shape of the profile you are cooling. For this example, we are cooling a cylindrically shaped PP strand and looking in a transport phenomena textbook [5, p. 440] we find the equation to determine the average Nusselt number to be:

\[
Nu = \left( 0.4 \times Re^{\frac{1}{2}} + 0.06 \times Re^{\frac{2}{3}} \right) \times Pr^{0.4} \times \left( \frac{\mu_\infty}{\mu_0} \right)\]

This equation can be used in the range of
Reynold number between 1 and 10,000
Prandtl number between 0.67 to 300
\(\mu_\infty/\mu_0\) between 0.25 and 5.2
Step 4 – Calculate Nusselt Number

- $Re = 3267.02$
- $Pr = 6.06$
- $\mu_{\infty, water, 95^\circ F} = 0.7198 \text{ cP}$
- $\mu_{0, water, 78^\circ F} = 0.878 \text{ cP}$

$$N_u_m = \left(0.4 * (3267.02)^{\frac{1}{2}} + 0.06 * (3267.02)^{\frac{2}{3}}\right) * (6.06)^{0.4} * \left(\frac{0.7198 \text{ cP}}{0.878 \text{ cP}}\right)^{\frac{1}{4}}$$

$$N_u_m = 70.6$$
Step 5 – Calculate convective heat transfer coefficient

- You must know your pellet strand’s “characteristic length” in order to calculate the convective heat transfer coefficient from the Nusselt number. This is simply the diameter of the strand which you can take from your die hole diameter.

- \( k = \text{conductive heat transfer coefficient of PP} = 0.16 \frac{W}{m \cdot K} \)

\[
h = \frac{Nu \cdot k}{L} = \frac{70.6 \cdot 0.16}{0.004778 \cdot \frac{2}{m \cdot K}} = 4,728.34 \frac{W}{m^2 \cdot K}
\]
Step 6 – Use Heisler Chart to calculate Fourier number

Now that we have the convective heat transfer coefficient, we can relate that to the amount of time we need to cool our strands to the desired temperature via a Heisler chart. There are multiple Heisler charts available for different shapes. The Heisler chart pictured below is one for a cylinder which is what we’ll use.

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**Figure 58.1** Centerline temperature as a function of time for an infinite cylinder of radius $r_e$ [1]. Used with permission.
Step 6 – Use Heisler Chart to calculate Fourier number

The Heisler chart requires that we calculate the inverse of the Biot number.

We do this by first calculating the inverse of the Biot number.

\[
\frac{1}{Bi} = \frac{k}{h * r_o} = \frac{0.16 \frac{W}{m * K}}{4,738.24 \frac{W}{m^2 * K} * \left(\frac{0.00478 m}{2}\right)} = 0.014
\]
Step 6 – Use Heisler Chart to calculate Fourier number

Then we calculate the approach temperature $\Theta^*$. If you need guidance on what your desired plastic temperature should be, you can search online for “softening points” of the polymer you are interested in and subtract 20 degrees from that. For polypropylene, I suggest 192° F as good enough but the desired temperature depends on the particular polymer and pelletizer capabilities.

$$\Theta^* = \frac{(T_{\text{plastic,desired}} - T_{\text{water}})}{(T_{\text{plastic,initial}} - T_{\text{water}})} = \frac{(192^\circ F - 78^\circ F)}{(420^\circ F - 78^\circ F)} = 0.31$$
Step 6 – Use Heisler Chart to calculate Fourier number

Now with our inverse Biot number and approach temperature, we can determine our Fourier number from the Heisler chart. I’ve found it’s best to try and derive a regression line for the inverse Biot number you’ve obtained from two points easily visible and determine your Fourier number from that instead of trying to squint your eyes and estimate. In the example attached, we see the Fourier number is around 0.32.
Step 7 – Calculate Water Bath Length

With the Fourier number, we can now calculate the time required for the plastic strands to reach the desired temperature.

\[ \alpha = \text{thermal diffusivity of PP} = 9.6 \times 10^{-8} \frac{m^2}{s} \]

\[ t = \frac{F_0 \times r_0^2}{\alpha} = \frac{0.32 \times \left(\frac{0.00478 \text{ m}}{2}\right)^2}{9.6 \times 10^{-8} \frac{m^2}{s}} = 18.77 \text{ s} \]

Now that we know the time required in the water bath, we can use the line speed calculated earlier to calculate the predicted water bath length.

\[ L_{\text{water bath}} = t \times \text{Line Speed} = 18.77 \text{ s} \times 2.500 \frac{ft}{s} = 47 \text{ ft.} \]
Ideas to shorten water bath length

Keep in mind that if your water bath length is longer than any space you have in your facility, you could attempt the following:

• Adjusting water bath roller set-up to make multiple passes in the water bath either length-wise or height-wise
• Purchasing or renting a chiller to lower the incoming water temperature if your cooling water temperature is above 72 degrees F
• Using spray bars to use evaporative cooling in order to cool the strands more
• Using multiple water baths to reduce thermal boundary layer
• Increasing water flow rate
Determining Effect of Lengthening Water Bath

You can try to evaluate what effect lengthening your water bath will have on decreasing pellet temperature.

What I would do is vary production rate and using your rollers on your water bath, vary the length at which the plastic strand or extrudate is inside the water bath

<table>
<thead>
<tr>
<th>ft. strands are in long waterbath</th>
<th>lbs/hr</th>
<th>Pellet Temperature °F</th>
<th>(°F)^2/(lbs/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.00</td>
<td>3781.30</td>
<td>217.03</td>
<td>12.46</td>
</tr>
<tr>
<td>27.00</td>
<td>3781.30</td>
<td>201.04</td>
<td>10.69</td>
</tr>
<tr>
<td>31.00</td>
<td>3781.30</td>
<td>191.90</td>
<td>9.74</td>
</tr>
<tr>
<td>31.00</td>
<td>2843.10</td>
<td>161.47</td>
<td>9.17</td>
</tr>
<tr>
<td>20.00</td>
<td>2843.10</td>
<td>184.60</td>
<td>11.99</td>
</tr>
<tr>
<td>16.00</td>
<td>2843.10</td>
<td>204.35</td>
<td>14.69</td>
</tr>
</tbody>
</table>
Relating Water Bath Length To Pellet Temperature

\[ y = -7.261 \ln(x) + 34.36 \]

\[ R^2 = 0.9584 \]
Determining Effect of Lengthening Water Bath

Then, with formula in hand, you can estimate what the pellet temperature will be at different production rates and different water bath lengths.

<table>
<thead>
<tr>
<th>Length strands are in long water bath (feet)</th>
<th>Ratio Calculated</th>
<th>Production Rate (lbs/hr)</th>
<th>Outlet Pellet Temperature °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>30.00</td>
<td>9.67</td>
<td>6035.46</td>
<td>241.55</td>
</tr>
<tr>
<td>40.00</td>
<td>7.58</td>
<td>6035.46</td>
<td>213.87</td>
</tr>
<tr>
<td>50.00</td>
<td>5.96</td>
<td>6035.46</td>
<td>189.64</td>
</tr>
<tr>
<td>60.00</td>
<td>4.64</td>
<td>6035.46</td>
<td>167.26</td>
</tr>
<tr>
<td>70.00</td>
<td>3.52</td>
<td>6035.46</td>
<td>145.67</td>
</tr>
</tbody>
</table>

Calculated from
\[ \sqrt{\text{Production Rate} \times \text{Ratio}} \]
Works Cited


Appendix
In order to get an estimate of the additional cooling required to accommodate the heat of fusion for crystalline polymers, you must first find the heat of fusion of the polymer (in the above table, it’s $\lambda$)

We’ll use polypropylene as an example.
Crystalline Polymer Addendum (Cont’d)

Let’s say we have a rate of 5,000 lbs/hr

This means that we would have the following amount of energy that needs to be removed due to heat of fusion

\[
5,000 \frac{lbs}{hr} \times \frac{1 \text{ kg}}{2.2046 \text{ lbs}} \times 259 \frac{kJ}{kg} \times \frac{1 \text{ hour}}{3600 \text{ s}} = 163 \text{ kW}
\]

Now there are two methods to remove this extra heat:

- More water flow to raise the convective heat transfer
- Lower temperature of the water

We’ll assume that it’s only convective heat transfer at work
Crystalline Polymer Addendum (Cont’d) – Setting up the convective heat transfer equation

Let’s say we have a rate of 5,000 lbs/hr

\[
Q = h \cdot A \cdot \Delta T
\]

\[
h = 2,364.17 \frac{W}{m^2 \cdot K}
\]

Surface area of the strands

\[
A = 2 \cdot \pi \cdot r \cdot L_{Bath} \cdot \text{number of strands}
\]

\[
2 \cdot \pi \cdot 0.00478 \, m \cdot 14.3 \, m \cdot 71 = 30.493 \, m^2
\]
Crystalline Polymer Addendum (Cont’d) – Lower Water Bath Temperature Route

If my incoming water temperature is 75°F (297 K), how much lower does it have to be remove that latent heat?

\[ Q = h \times A \times (T_{normal} - T_{needed}) \]

\[ T_{normal} - \frac{Q}{h \times A} = T_{needed} \]

\[ 297 \text{ K} - \frac{163,169 \text{ W}}{2,364.17 \left( \frac{W}{m^2 \times K} \right) \times 30.493 \text{ m}^2} = 294.7 \text{ K or 70.8°F} \]
Crystalline Polymer Addendum (Cont’d) – Lengthen Water Bath Route

First you find how much heat needed to be dissipated for your plastic

\[
T_{\text{die}} = 420^\circ F \text{ or } 488.7 \text{ K} \quad \& \quad T_{\text{final}} = 192^\circ F \text{ or } 362.0 \text{ K}
\]

\[
Q = h \times A \times (T_{\text{die}} - T_{\text{final}})
\]

\[
Q = 2,364.17 \frac{W}{m^2 \times K} \times 30.493 \ m^2 \times (488.7 \text{ K} - 362.0 \text{ K})
\]

\[
Q = 9,133,883.6 \ W
\]

Compared to the heat needed to be removed due to latent heat, that’s a difference of:

\[
\frac{163,169 \ W}{9,133,883.6 \ W} \times 100\% = 1.8\%
\]

Therefore, you can increase the length of the bath by 2% if you’d like
Crystalline Polymer Addendum (Cont’d) – Increase Water Flow Rate Route

You could increase the flow rate of water. Doing this:

1. Increases the Reynolds Number which
2. Increases the Prandtl Number which
3. Increases the Nusselt Number which
4. Increases your convective heat transfer coefficient which
5. Increases the amount of energy you are able to remove by heat which
6. Allows you to use the same length water bath

So how much do you need to increase the flow of water by in order to negate the effect of the latent heat of fusion?

Frankly, it’s best just to trial and error because the increase in flow affects so many other factors such as temperature
In summary:

- radiation = generated and absorbed photons
- conduction = molecules exciting their neighbors successively
- convection = molecules heated like in conduction, but then move to another location
Relationship of Area to Velocity

Remember

\[ Q = v \times A \]

\[ Q = \text{volumetric flow rate}, v = \text{velocity}, \text{and } A = \text{area} \]

So the smaller the area a fixed volumetric flow rate of fluid has to go through, the higher the velocity. The higher the velocity, the more likely you are to be in turbulent flow. If in turbulent flow, you get an additional mechanism of heat transfer in the radial and azimuthal directions as opposed to laminar flow which only offers heat transfer in the axial or main flow direction.
Laminar vs. Turbulent Flow

\[ Re = \frac{\text{inertia forces}}{\text{viscous forces}} = \frac{\rho \cdot V \cdot D}{\mu} \]

- **Laminar Flow**
  - Smooth, streamlined flow

- **Turbulent Flow**
  - Chaotic, swirling flow

Factors affecting Re:
- Velocity
- Characteristic dimension
- Density
- Viscosity

ExtrusionConference.com
Explaination:

In Laminar flow, fluid particles flow in an orderly manner along certain pathlines. So, the only means by which heat is transferred between different streams is through *Molecular diffusion* i.e. movement of molecules from region of higher concentration to lower concentration.

In Turbulent flow, the fluctuations provide an additional mechanism for Heat transfer in addition to the Molecular diffusion. The eddies (as shown in the pic) are formed due to these fluctuations. These eddies rapidly transport mass, momentum and energy across different regions of the flow. Compared to the eddies, molecular diffusion is a very slow process and is often neglected in calculating the heat transfer rate in Turbulent flows. Hence, the turbulent flows always have a higher heat transfer coefficient compared to the Laminar flows.
**Prandtl Number**

The relative thickness of the velocity and the thermal boundary layers is best described by the *dimensionless* parameter Prandtl number.

\[
\text{Pr} = \frac{\text{Molecular diffusivity of momentum}}{\text{Molecular diffusivity of heat}} = \frac{v}{\alpha} = \frac{\mu c_p}{k}
\]

<table>
<thead>
<tr>
<th>Fluid</th>
<th>Pr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid metals</td>
<td>0.004–0.030</td>
</tr>
<tr>
<td>Gases</td>
<td>0.19–1.0</td>
</tr>
<tr>
<td>Water</td>
<td>1.19–13.7</td>
</tr>
<tr>
<td>Light organic fluids</td>
<td>5–50</td>
</tr>
<tr>
<td>Oils</td>
<td>50–100,000</td>
</tr>
<tr>
<td>Glycerin</td>
<td>2000–100,000</td>
</tr>
</tbody>
</table>

The Prandtl numbers of gases are about 1, which indicates that both momentum and heat dissipate through the fluid at about the same rate.

Heat diffuses very quickly in liquid metals (Pr << 1) and very slowly in oils (Pr >> 1) relative to momentum. Consequently, the thermal boundary layer is much thicker for liquid metals and much thinner for oils relative to the velocity boundary layer.
Thermal Boundary Layer Thickness

\[ \delta \]

\[ x \]

- \( Pr << 1 \)
- \( Pr = 1 \)
- \( Pr >> 1 \)
Fig. 4.4: The relation of two boundary layers at different Pr numbers
Thermal Boundary Layer

Similar to velocity boundary layer, a thermal boundary layer develops when a fluid at specific temperature flows over a surface which is at different temperature.

\[
\begin{align*}
\text{Pr} > 1 & \quad \delta > \delta_T \\
\text{Pr} = 1 & \quad \delta = \delta_T \\
\text{Pr} < 1 & \quad \delta < \delta_T
\end{align*}
\]

Fig. 3: Thermal boundary layer.

The thickness of the thermal boundary layer \( \delta_t \) is defined as the distance at which:

\[
\frac{T - T_s}{T_\infty - T_s} = 0.99
\]

The relative thickness of the velocity and the thermal boundary layers is described by the Prandtl number.

For low Prandtl number fluids, i.e. liquid metals, heat diffuses much faster than momentum flow (remember \( Pr = \nu/\alpha \ll 1 \)) and the velocity boundary layer is fully contained within the thermal boundary layer. On the other hand, for high Prandtl number fluids, i.e. oils, heat diffuses much slower than the momentum and the thermal boundary layer is contained within the velocity boundary layer.
I think you are spending too much time trying to ascribe some physical significance to Pr. My advice is just to accept that it is equal to the ratio of the kinematic viscosity to the thermal diffusivity, and move on. But pay attention to how it comes into play in actual heat transfer situations that you study such as in fully developed laminar flow heat transfer in a tube or, as you've shown, heat transfer to a fluid in flow over a flat plate.

At high Pr (like liquids), the thermal boundary layer lies inside the velocity boundary layer, but at very low Pr, the thermal boundary exceeds the velocity boundary layer in thickness.
Physical State Transitions

Amorphous Polymer  Crystalline Polymer

Liquid
Gum
Rubber
Glass
Flexible Thermoplastic

Increasing Temperature

$T_g$

$T_m$

$T_g$

Fig. 4.2-1  Specific heat – temperature characteristic of polycarbonate
**Figure 2.** Crystallinity extrapolated heat capacity of amorphous and crystalline polypropylene. The drawn-out curve represents the best estimate for the heat capacity of crystalline polypropylene between $T_c$ and $T_m$. The increase is similar to the heat capacity increase of crystalline polyethylene also shown in the figure.
**Characteristic Length**

Characteristic length $\equiv \frac{V}{A}$

Path of least thermal resistance

Characteristic length $\downarrow$
= Temperature can be changed in short time

$$\frac{hL}{k} < 0.1 \quad (8)$$

*Figure 4. Characteristic lengths for heat conduction in various geometries.*
Table 5.1: Geometry, characteristic length, and Biot number definition

<table>
<thead>
<tr>
<th></th>
<th>Infinite slab</th>
<th>Long cylinder</th>
<th>Sphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristic length</td>
<td>1/2 thickness</td>
<td>Radius</td>
<td>Radius</td>
</tr>
<tr>
<td>Biot number (Bi)</td>
<td>$hL/k$</td>
<td>$hR/k$</td>
<td>$hR/k$</td>
</tr>
</tbody>
</table>

Return to slide 18
<table>
<thead>
<tr>
<th>Flow type</th>
<th>(W/m² K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forced convection; low speed flow of air over a surface</td>
<td>10</td>
</tr>
<tr>
<td>Forced convection; moderate speed flow of air over a surface</td>
<td>100</td>
</tr>
<tr>
<td>Forced convection; moderate speed cross-flow of air over a cylinder</td>
<td>200</td>
</tr>
<tr>
<td>Forced convection; moderate flow of water in a pipe</td>
<td>3000</td>
</tr>
<tr>
<td>Forced Convection; molten metals</td>
<td>2000 to 45000</td>
</tr>
<tr>
<td>Forced convection; boiling water in a pipe</td>
<td>50,000</td>
</tr>
<tr>
<td>Forced Convection - water and liquids</td>
<td>50 to 10000</td>
</tr>
<tr>
<td>Free Convection - gases and dry vapors</td>
<td>5 to 37</td>
</tr>
<tr>
<td>Free Convection - water and liquids</td>
<td>50 to 3000</td>
</tr>
<tr>
<td>Air</td>
<td>10 to 100</td>
</tr>
<tr>
<td>Free convection; vertical plate in air with 30°C temperature difference</td>
<td>5</td>
</tr>
<tr>
<td>Boiling Water</td>
<td>3.000 to 100.000</td>
</tr>
<tr>
<td>Water flowing in tubes</td>
<td>500 to 1200</td>
</tr>
<tr>
<td>Condensing Water Vapor</td>
<td>5.0 - 100.0</td>
</tr>
<tr>
<td>Free convection</td>
<td>100 to 1200</td>
</tr>
<tr>
<td>Oil in free convection</td>
<td>50 to 350</td>
</tr>
</tbody>
</table>

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Straight Through Set-Up

Double-Back Rod
Double Back Set-Up

Double-Back Rod