Holding Tube Design Guideline

The Institute for Thermal Processing Specialists is a non-profit organization established exclusively for the purpose of fostering education and training for those persons interested in procedures, techniques, and regulatory requirements for thermal processing of all types of food or other materials, and for the communication of information among its members and other organizations.

Part of the mandate of IFTPS Technical Committees is to develop protocols to be used as guides for carrying out the work of thermal processing specialists. This guideline was prepared by an ad hoc committee of Institute and reviewed extensively by members of the Institute.

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The following recommendations are to be considered voluntary guidelines. While this does not preclude the application of other methods and equipment, these guidelines have been developed by consensus of the Institute for Thermal Processing Specialists and should be given serious consideration for adoption as methodology for design, construction, and verification of holding tubes.

1 INTRODUCTION

Many processes used in the food processing industry involve holding a product for a specific amount of time at a given set of conditions. This includes blanching, cooking, starch blooming, caramelization, protein denaturization, hydration, enzyme deactivation, and reduction of microorganisms. These processes can be done either using batch or continuous processing.

A holding tube is a fixed length of piping or tubing. In continuous processes a holding tube is typically used to ensure a product is held at a set of conditions for a specific amount of time. The objective of this guideline is to define best practices and key regulatory requirements regarding design of holding tubes.

2 SCOPE

This guideline covers design of holding tubes for homogeneous (or near homogeneous) product and consistent conditions (temperature and flow profile), across and along the tube as well as over time. Assumptions generally include:

- Temperature – consistent across tubing starting at entrance and minimal heat loss.
- Composition – any reactions (e.g., starch blooming, enzyme deactivation, protein denaturing) do not affect any change to temperature, holding time requirements or flow regime and are the same for every portion of the product.
- Rheology – worst case (normally most viscous) or changes do not affect flow regime.
- Particles – small enough to not effect a change to flow regime and heat penetration is not a factor.

Various methods may be employed to account for inconsistent conditions such as variation in temperature, flow regime and/or residence time. These methods can include computational fluid dynamics (CFD) analysis, use of static mixers, or location of monitoring instruments. Each application should be evaluated by a subject matter expert with experience in holding tube design and construction for the magnitude of the variations and the assumptions and methods used.

This guideline is focused on the design of holding tubes for food safety purposes (i.e., reduction of microorganisms.) It may also be used for a holding tube or the portion of a holding tube that is for non-food safety purposes (e.g., the extended holding of yogurt milk.)

This guideline does not cover design of holding tanks, which may be used for extremely long holding times.

3 Definitions

Average velocity (v_{avg}) – the velocity based on the physical dimensions of the holding tube (inside cross-sectional diameter) and the product volumetric flow rate.

Average (volumetric) residence time (t_{avg}) – residence time based on the average velocity and holding tube length.

Correction factor (CF) – A dimensionless factor used to calculate the fastest particle velocity or residence time from the average.

Cut-out – the value at which an automated system takes an action [e.g., maximum (cut-out) flow or minimum (cut-out) temperature.]

Fastest particle – The particle of product that has the highest velocity (v) and therefore the lowest (minimum) residence time (t) in the holding tube.

Fastest particle velocity (v_{max}) – The velocity of the fastest particle.

Fastest particle residence time – see minimum residence time.

Flow profile or pattern – The shape of the velocity profile in the holding tube based on product characteristics, hold tube dimensions, and flow rate. Used to determine one of the correction factors.

Holding tube – a length of pipe or tubing without any additional external heating that is used to give continuous holding of every particle of food for at least the minimum residence time required to achieve the objective of a (thermal or other) process.

Holding time – see residence time.

Required length (L_{req}) – Minimum length of the holding tube needed to meet the required residence time (t_{req}) at fastest particle's velocity (v_{max}).

Minimum residence time (t_{min}) – the residence time in the holding tube of the fastest particle based on its velocity (including applicable correction factors) and the holding tube length. This should be higher than the required residence time (t_{req}).

Required residence time (t_{req}) – The minimum time required for each particle of food to achieve the objective of the (thermal or other) process. Also referred to as minimum required residence time.

Residence time (holding time) (t) – the time (minimum, required or actual) a particle of food is exposed to a set of process conditions (e.g., temperature) in the holding tube.

Validation – the collection and evaluation of data, from the process design stage through commercial production, which establishes scientific evidence that a process is capable of consistently delivering quality product. (Guidance for Industry Process Validation: General Principles and Practices, FDA, January 2011)

Verification – Confirmation by examination and provision of objective evidence that specified requirements have been fulfilled. (NFPA Bulletin 43-L, 2nd ed. Validation Guidelines for Automated Control of Food Processing Systems Used for the Processing and Packaging of Preserved Foods, National Food Processors Association, 2002)

4 Basis for Holding Tube Design

The basis for holding tube design is that the volume of a given length of tubing results in a specific "dwell" or residence time for a particle or finite volume of product. This ensures that the product is exposed to the specific conditions for the required time (t_{req}). Mathematical models have been developed and are accepted to calculate the minimum residence time of the product in the holding tube. The volume may be accurately calculated based on measurements of the diameter and length of the tubing inside. The time the product is in the tube (residence time) can then be calculated using the known volume, the flow rate of the product, and correction factors for specific operating conditions.

The required residence time will vary depending on the desired results of the process and the operating conditions (e.g., the scheduled process, process letter, regulatory requirement). Generally, higher operating temperatures will require less holding time to achieve the same results. The required residence time is normally calculated based on generally accepted formulas and criteria. It may also be taken from published tables (e.g., US Grade "A" Pasteurized Milk Ordinance (PMO)), which were most likely derived from similar calculations or individual tests.

An example is the formula used for determining the process lethality.

$$F_{T_R} = t_{req} \times 10^{((T-T_R)/z)}$$

F_{TR}: time required at a reference temperature to achieve a given log reduction of the target organism or other aspect (e.g., enzymes) [min]

t_{req}: minimum residence time required for every "particle" at the operating temperature [min]

T: minimum operating temperature [°C, °F]

T_R: reference temperature [°C, °F]

z: temperature coefficient [°C, °F]

F_{TR} is based on an expected starting concentration and a food safety objective end point. F_{TR} and z are both based on experimental data.

Note: The required residence time (t_{req}), as well as other design criteria noted below, should be specified by a subject matter expert with experience in the required process and in holding tube design and construction. The required time should follow local regulations where the product will be sold.

5 Holding Tube Calculations

Calculations surrounding a holding tube are based on the relationship:

$$L = v \times t \times CF \qquad \text{(eq. 1)}$$

Where:

L: Holding tube length

v: Velocity in the holding tube

t: Residence time

CF: Correction factor (see below)

The velocity of the fastest particle in the tube is determined using the holding tube diameter, the volumetric flow, and several correction factors which are detailed in the following sections. From this velocity, one can calculate either the required length (from the required residence time) or the residence time (from the actual holding tube length).

The residence time is sometimes referenced by just an average or volumetric time. However, to ensure proper calculation of the residence time or holding tube length, the time should be specified as being based on specific correction factors. For example, the specification should indicate if the required residence time is for the fastest particle or the average time for the bulk product – e.g., 4 seconds laminar corrected (fastest particle); 15 seconds volumetric (average time).

Examples of the calculations and comparisons of different options are in Section 11.

5.1 Calculations Steps

The minimum holding time calculation normally is executed in five steps:

1- Determination of volume correction factors (e.g., product thermal expansion, direct steam addition),

2- Calculation of the average particle velocity without flow profile correction factor,

3- Determination of required flow pattern correction factors,

4- Calculation of fastest particle velocity (V_{max})

5- Calculation of required holding tube length (L_{req}) or residence time of the fastest particle (t_{min}).

It is critical to review the dimensions / units of all parameters for consistency.

5.2 Step 1a: Determining Product Thermal Expansion Correction Factors:

The product density is dependent on temperature. In food products, the density normally decreases with increasing temperature. As consequence, in the continuous thermal process, the increase of temperature will result in an increase of product volume in the pipes. The increase of product volume will result in acceleration of the product particles in the pipe. Since the product flow is measured at the flow meter or metering pump and calculations are based on the product velocity in the holding tube, the flow correction factor to calculate the maximum velocity the ratio of the density at the temperature of the product at the flow meter or metering pump to the density at the temperature of the product in the holding tube as in equation 2.

$$CF_{Therm} = \rho_{\text{flow meter temperature}} / \rho_{\text{holding tube temperature}} \quad \text{(eq. 2)}$$

Where:

ρ: density of the product at the given temperature

As the main component of most liquid foods is water, it is acceptable to calculate the thermal expansion correction factor using water density at both points. This information can come from steam tables.

When the flow meter is located at the holding tube inlet, the correction factor would be equal to one (CF_{Therm} = 1.0).

Notes:

1- The product thermal expansion is typically ignored (CF_{Therm} = 1.0) for volumetric calculations, which are used for some markets, products and/or organizations (e.g., for acid foods).

2- A default value of 6% (CF_{Therm} = 1.06) is used by some organizations for product thermal expansion based on a temperature increase of water of 160-290 F. Use of default values instead of calculations should be evaluated by a subject matter expert.

5.3 Step 1b: Determining Direct Steam Heating Correction Factors:

For direct heating system applications (i.e., steam injection or infusion), the addition and condensation of steam will result in a larger amount of fluid flowing across the pipe, increasing the velocity. For direct heating systems it is appropriate to include a correction factor for the volume of steam added (CF_{Steam}) calculated as in equation 3a.

$$CF_{Steam} = 1 + \frac{\Delta T \times C_p}{\Delta H_{vap}} \quad \text{(eq. 3a)}$$

Where:

ΔT: Temperature rise due to the addition of steam [°C, °F]

C_p: Specific heat of the product [J/kg °C, BTU/lb °F]

ΔH_{vap}: Heat of evaporation of steam [J/kg, BTU/lb]

Because the heat capacity (energy that is added to heat the material) of water is higher than most foods, it is acceptable to use heating of water to determine the correction factor for steam addition. It is also accepted to use the properties of saturated steam at the holding tube temperature. Both proprieties can be obtained from steam tables. For water heated to approximately 140 °C (284 °F) the correction factor is approximately 1% per 10°F (0.56°C):

$$CF_{Steam} = 1 + \frac{\Delta T}{1000}\ (°F)\ or\ 1 + \frac{1.8 * \Delta T}{1000}\ (°C) \quad \text{(eq. 3b)}$$

For indirect heating systems the correction factor would be equal to one (CF_{Steam} = 1.0).

Note:

1. Steam for direct heating should be saturated and dry (no condensate or superheat).
2. A default value of 12% (CF_{Steam} = 1.12) is used by some organizations for the amount of steam added. This is based on the amount of 80 PSIG saturated steam needed to increase the temperature of water of 180-290 F. Use of default values instead of calculations should be evaluated by a subject matter expert. The holding tube sizing tables in the US PMO for direct heating are based on this default value.

5.4 Step 1c: Holding tube thermal expansion

The dimensions of the holding tube are normally measured at ambient temperature. The holding tube material will expand in both length and diameter when at operating temperature. This will increase the volume decreasing the velocities and increasing the residence time. Because calculating this increase adds complications to the calculations, it is usually considered to be a safety factor and not included in calculations.

5.5 Step 2: Calculation of Average Velocity

The average holding time is calculated based on volumetric flow rate and holding tube physical dimensions.

Average flow velocity (v_{avg}) is calculated using equation 4:

$$v_{avg} = \frac{4 \times Q}{\pi \times (\,D_i^{\,2})} \times CF_{Therm} \times CF_{Steam} \qquad \text{(eq. 4)}$$

Where:

v_{avg}: average particle velocity [m/s; ft/min]

Q: product maximum* volumetric flow rate [l/h, m^3/s, gal/min]

D_i: holding tube internal diameter [cm, mm, in]

*Note: the product maximum flow rate refers to the maximum allowed product flow (cut-out flow) rate in the equipment.

Note: Some markets, products and/or organizations use the average residence time and velocity to calculate the holding tube size. It is important to clarify that the average flow velocity **does not** represent the maximum (fastest) particle speed in the product and average residence time **does not** represent the minimum particle residence time in the holding tube, **even if the maximum flow rate was used.**

5.6 Step 3: Determining Flow Pattern Correction Factors

The calculation of the average velocity is based on a "ideal" flat velocity profile (plug flow) where all particles move at the same velocity in the pipe (see figure 5.1) However, this does not consider the impact of the product properties or pipe dimensions on the flow pattern,

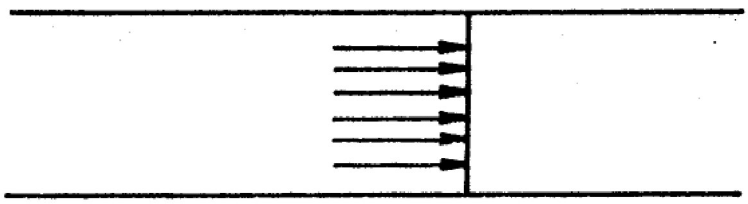


Fig 5.1 Velocity profile for a plug flow (source: Nelson 2010; Principles of Aseptic Processing & Packaging)

In the actual food matrix, the particles move with different velocities, resulting in a flow pattern which is different from plug flow. The fastest moving particles are considered as the worst-case (lowest residence time) scenario from a calculation perspective.

The mechanics of fluids defines the flow of any fluid through a pipe as occurring in one of 2 ways:

1- Laminar Flow (or Streamline flow): the elements of fluid flow as concentric shells in an organized pattern, with lower resistance to the flow in the center. This pattern results in a parabolic flow profile.

2- Turbulent Flow: there is radial mixing across the pipe, partially flattening the flow profile.

The two-flow pattern profiles are represented in figure 5.2:

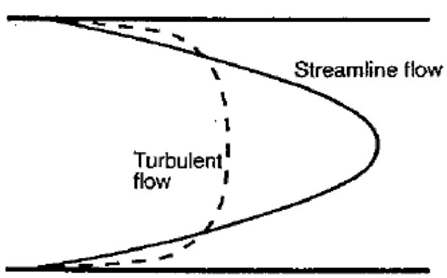


Fig 5.2: Comparison of velocity profiles of laminar and turbulent flow (source: Lewis & Heppell 2000; Continuous Thermal Process of Foods)

Quantification of the flow regime is critical for the determination of the processing temperatures and holding times. Dimensionless Reynolds Number (N_{Re}) is used to predict and identify the flow regimes. This number is defined as the ratio of fluid momentum force (inertial forces) to viscous shear forces. The point at which the flow regime changes from Laminar to Turbulent can be predicted by using the Reynolds Number (eq 5):

$$N_{Re} = \frac{\rho \times v_{avg} \times D_i}{\mu} \quad \text{(eq. 5)}$$

Where:

N_{Re} or Re:	Reynolds Number [Dimensionless]
ρ:	product density [kg/m^3, lb/ft^3]
v_{avg}:	average flow velocity (same calculated in step 1) [m/s; ft/min]
D_i:	holding tube internal diameter [cm, mm, in]
μ:	fluid viscosity [cps, mPa sec]

As consequence of these flow patterns, product particles have different velocities across the pipe. Therefore, a correction factor should be applied to the average velocity (V_{avg}) to account for these different velocities. Mathematical modeling based on the empirical power law velocity profile (e.g., Bird, et al. 1960) has led to the acceptance of the following flow profile corrections factors ($CF_{profile}$):

Laminar Flow: maximum particle velocity will be twice the average velocity.

$$CF_{profile} = 2.0 \quad \text{(eq. 6a)}$$

Turbulent Flow: maximum particle velocity will be 20% higher than the average velocity.

$$CF_{profile} = 1.2 \quad \text{(eq. 6b)}$$

Classical mechanics of fluids defines the end of the Laminar Flow profile when $N_{Re} < 2100$, and the beginning of the Turbulent Flow when $N_{Re} > 4000$. Fluids with N_{Re} between 2100 and 4000 are considered to be in a transition state, with part of the particles with behavior close to laminar flow pattern and part with close to turbulent flow pattern. As there is a possibility some particles have a maximum velocity as in laminar flow pattern, the correction for the laminar flow pattern should be used for fluids with $N_{Re} < 4000$ to ensure the worst case was considered.

Notes:

1- The fastest particle correction is ignored ($CF_{profile} = 1.0$) for volumetric calculations.

2- Many food products exhibit non-Newtonian rheologic properties. However, most products are either Newtonian or are nearly Newtonian at the temperatures in the holding tube. More complex calculations and considerations apply to non-Newtonian fluids. Each application should be evaluated by a subject matter expert with experience in holding tube design and construction for the magnitude of the variations and the assumptions and methods used.

3- Determination of product density and rheological properties should use appropriate methodologies. Both are dependent on the product temperature and density and may be dependent on pressure if any gas is entrained in the product. The methodology should be consistent with intended use. Regulatory agencies or Process Authorities could have specific requirements to validate the product density or viscosity as critical limits.

4- Some regulatory agencies and Process Authorities have different requirements for the minimum N_{Re} for turbulent flow. For example, the US Food and Drug Administration (US FDA) specifies a Re of >4000 for turbulent flow while the European Hygienic Engineering & Design Group (EHEDG) specifies >2300.

5- Specific corrective factors could be required by Regulatory Agencies for some applications.

5.7 Step 4: Calculating Maximum Velocity

Applying the correction factors above to the average velocity we achieve the velocity of the fastest moving particle (v_{max}) as in equation 7:

$$v_{max} = v_{avg} x\, CF_{Profile} \qquad \text{(eq. 7)}$$

Using the normal flow profile correction factors, the calculation is:

Laminar flow:

$$v_{max} = v_{avg} \times 2.0 \qquad \text{(eq. 7a)}$$

Turbulent flow:

$$v_{max} = v_{avg} \times 1.2 \qquad \text{(eq. 7b)}$$

5.8 Step 5a: Calculating the Minimum Residence time:

The residence time for the fastest moving particle (t_{min}) in a holding tube is obtained by dividing the measured holding tube length (L) by the velocity of the fastest moving particle (v_{max}):

$$t_{min} = \frac{L_{act}}{v_{max}} \qquad \text{(eq. 8)}$$

Average (volumetric) residence time (t_{avg}) can be calculated using equation 8a. This is the same as not applying the flow profile correction factor in steps 3 and 4.

$$t_{avg} = \frac{L_{act}}{v_{avg}} \qquad \text{(eq. 8a)}$$

Where:

t_{avg}: average (bulk) residence time [min, sec]

L_{act}: actual holding tube length [m, ft, in]

The residence time of the fastest moving particle (t_{min}) can also be calculated using the flow profile correction factors and the average residence time (t_{avg}) as below:

$$t_{min} = t_{avg} \,/\, CF_{Profile} \qquad \text{(eq. 9)}$$

Using the normal flow profile correction factors, the calculation is:

Laminar Flow:

$$t_{min} = t_{avg} \times 0.50 \qquad \text{(eq. 9a)}$$

Turbulent Flow:

$$t_{min} = t_{avg} \times 0.83 \qquad \text{(eq. 9b)}$$

5.9 Step 5b: Calculating Required Holding Tube Length

During design of the holding tube, the required minimum length of the holding tube (L_{req}) is obtained by multiplying the required residence time for the fastest moving particle (t_{req}) by the velocity of the fastest moving particle (v_{max}).

$$L_{req} = t_{req} \times v_{max} \qquad \text{(eq. 10)}$$

For volumetric flow calculations, the minimum required length (L_{vol}) can be calculated using equation 10a. This is the same as not applying the flow profile correction factor in steps 3 and 4.

$$L_{vol} = t_{avg} \times v_{avg} \qquad \text{(eq. 10a)}$$

Where:

L_{vol}: required holding tube length for volumetric calculations [m, ft, in]

The actual holding tube length (L_{act}) should always be longer than the required length (L_{req} or L_{vol}).

6 Design and Construction of Holding Tubes

6.1 Holding tube shape

Holding tubes are typically either trombone shaped (straight sections connected by u-bends) or spiral shaped (coiled). Other shapes, such as going along the walls of a room, are acceptable if they meet the applicable requirements of this guideline.

6.2 Holding tube cross section

The cross section of the holding tube (i.e., diameter) should be chosen to ensure homogeneous conditions across the holding tube. Consideration should be given to accumulation of air or other gasses and to settling of suspended solids (e.g., undissolved powders).

Note: For some products, product buildup may effectively reduce the diameter of the holding tube and may be considered in selection of the diameter used for calculations and in operation (cleaning frequency).

When a holding tube has sections with different diameters, the calculations of holding time or length should be done separately for each section. Consideration should be given to slope (i.e., accumulation of air or other gases) and drainability in the transitions between sections while considering possible regulatory requirements.

Static mixers or corrugation of the holding tube have been used to mitigate separation or striation within the product. However, there is no consensus on the effect on flow pattern (plug, laminar or turbulent flow) or velocity (cross sectional area).

6.3 Slope

The calculations for holding time or holding tube length are based on the tubing being filled with the fluid (product) flowing through it. If there is something (i.e., air) in the tube that takes up part of the diameter, the velocity of the fluid will increase and the residence time will decrease. Holding tubes should be designed to encourage any material, usually gases (i.e., air), that is less dense than the product to flow up and out of the holding tube. In a properly designed holding tube, a small number of entrained bubbles in the product is assumed to travel at the same velocity as the product flow and not accumulate in the holding tube. Therefore, they will not significantly affect the residence time.

To avoid accumulation of air or other gasses when a holding tube has sections with different diameters, the transitions between the sections should have the same or higher slope on the top as the rest of the sections. This can be accomplished using eccentric reducers with the “flat” side on the top. Also, placing the smaller diameter pipe/tube at the outlet end of the holding tube can facilitate the design to address air or other gasses accumulation, particle settling and drainability.

The optimum configuration is to have a continuous upward slope from the beginning (inlet) of the holding tube to the end (outlet). This will minimize the risk of air accumulating in a section of the holding tube. However, this will result in a taller structure.

Holding tube sections that are designed to be flat (not have a slope) may be acceptable in some applications, jurisdictions, or organizations. However, they have a risk that the physical installation will have high points where gases (i.e., air) will accumulate. This could be due to problems in construction or installation, or to sagging of the lengths.

Holding tubes can be designed and constructed with interconnections that slope downward between multiple sections of tubing that are flat or sloped upward. This is often done for multiple length holding tubes or to reduce the overall height of the structure. Because of the likelihood that, in a downward sloping section, any air will travel at a different velocity than the product, any downward sloping section should not be included in the holding tube length measurement.

At a minimum, the holding tube should have a net positive slope – the outlet should be higher than the inlet.

6.4 Adjustable (Multiple) Length Holding Tubes

A system may require multiple holding tube lengths (different minimum residence times) for different flow rates or products. This can be accomplished by two methods. Each section or combination should meet the applicable requirements of this guideline.

6.4.1 Replacement

There is a complete holding tube for each required residence time and flow combination. Each holding tube will be of different lengths and possibly of different diameters. The holding tubes will have a set of swings connections (elbows or flow plate) at the inlet and the outlet. The inlet instrumentation (e.g., temperature, flow) will be before the inlet swings and the outlet instrumentation (e.g., temperature and pressure) will be after the outlet swings.

The same holding tube may be used for more than one combination of flow and time if the proper correction factors (e.g., laminar fastest particle correction) are applied to each. For example, a single holding tube can be used of both 2000 lph at 4 seconds and 4000 lph at 2 seconds.

Each holding tube should be validated for the required length.

6.4.2 Add-on

There are multiple sections of holding tube that can be combined with swing connections to yield the different required residence time. The various sections are typically the same diameter but may have different diameters.

The smallest (shortest) section is usually always used and therefore is fixed in place at the outlet of the holding tube. Additional sections are added to achieve the required residence time. For example:

A (fixed) = 2000 lph @ 2 sec.
A + B = 2000 lph @ 4 sec. or 4000 lph @ 2 sec.
A + B + C = 2000 lph @ 8 sec. or 4000 lph @ 4 sec.
A + B + C + D = 3600 lph @ 8 sec.

Each combination of holding tubes should be validated for the required length.

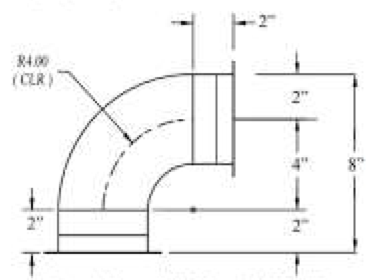
6.4.3 Swing connections and reducers

Swing connections and reducers, when used, should not be included in the length measurement unless it meets all applicable portions of this guideline.

6.5 BENDS

Bends should be included as part of the holding tube length. Any turbulence created by the change in direction is not considered in the residence time calculation.

The center line of the bend should be used for measuring the length of a bend. The length of a bend will depend on the center line radius (CLR) of that bend and the angle. The CLR of a bend is typically described as a multiple of the tubing diameter. Typical commercial elbows are short radius (1.0 diameter radius), long radius (1.5 diameter radius) and sweep (often 3 diameter radius). Tables with dimensions are available from fitting manufacturers for the bends supplied by them. Identify whether the lengths specified are for the bent portion only or include any straight ends.



Example shown: 4" 90° Elbow 1.0 CLR = 4"

Note: Some organizations use the inner curve or other calculations for a more conservative equivalent length.

6.6 MATERIAL

The holding tube should be made from material that is suitable for the intended use including the product(s), sanitation or sterilization and cleaning. The material should be non-toxic, and components should not migrate to the product. The material finish should be suitable for the intended use.

Consideration should be given to corrosion from product and CIP chemicals. Higher grade materials (e.g., low carbon, higher grade alloys, etc.) should be used where corrosion is a concern. Note that in some cases, it may be preferable to use a less expensive, lower grade of material and replace the holding tube periodically. This should only be done if the corrosion does not affect the cleanability of the holding tube.

6.7 WELDS

The holding tube assembly should be welded where possible. Unions (e.g., clamps) should be used only when required to meet design requirements (e.g., instrument insertion, sample or inspection connections, and interconnection of sections for varying the length).

The weld quality (e.g., alignment, finish) should be suitable for sanitary use. Automatic welding should be used where possible. Welders should be qualified on the equipment used. Test coupons should be made and inspected daily. Grinding and polishing of the exterior of weld is not required. The exterior, and interior, when possible, of all welds should be inspected before any grinding and polishing is performed.

6.8 SUPPORTS

Supports for holding tubes should be provided to maintain all parts of the holding tube in a fixed position, free from lateral or vertical movement. The supports should be designed to allow thermal expansion of the holding tube and to avoid erosion due to vibration.

The individual coils of spiral coiled holding tubes may rest on each other without separate supports. Guides should be supplied to keep the coils aligned.

6.9 HEAT LOSS/GAIN AND INSULATION

The holding tube should be designed and installed so no portion between the inlet and the outlet is heated. If the holding tube is in the same cabinet with a heating section, the holding tube should be located so the heater does not add heat to the holding tube.

The holding tube should be designed and installed such that heat loss from the surface of the holding tube is minimized or there is sufficient cross-sectional mixing in the holding tube to ensure that the outer portion of the product is not at a significantly lower temperature than the rest of the product. There should be no condensate drip on the tube and the tube should not be subjected to drafts or cold air.

Holding tubes are sometimes insulated and/or shrouded (a covering structure) to reduce heat loss or for personnel protection. Removable shrouding, with or without insulation, is acceptable. Pipe insulation is NOT recommended. Pipe insulation makes it difficult to inspect the holding tube and detect issues such as possible leaks. Inspection should therefore be performed before installation of insulation materials. Periodic inspection may be required by regulatory authorities to ensure it continues to meet requirements. Also, pipe insulation can be easily damaged, resulting in a non-hygienic installation due to harboring of vermin or water saturation allowing microbial growth. Water saturation can also result in additional heat loss.

6.10 REGULATORY REQUIREMENTS

Many regulations, standards, and guidelines, including those from US FDA (21 CFR 113, US PMO), the Codex Alimentarius Commission (CODEX), 3-A Sanitary Standards Inc (3-A) and EHEDG, contain design and construction requirements. The applicable local regulations should apply and may override the recommendations in this guideline. Examples are:

- Holding tube materials and finishes should meet the local requirements for food contact materials.
- A holding tube for food safety purposes should have a continuous upward slope of not less than 2.1 centimeters per meter (0.25 inches per foot).
- Supports for holding tubes should be provided to maintain all parts of the holding tubes in a fixed position, free from any lateral or vertical movement.
- No device should be permitted for short-circuiting the portion of the holding tube required for food safety purposes.
- The holding tube should be so designed that no portion between the inlet and the outlet is heated.
- The holding tube should be drainable.

7 ASSOCIATED INSTRUMENTATION

Instruments associated with the holding tube are critical for proper application of a thermal process. This includes instruments to measure flow, temperature, and pressure. Care should be taken in the selection, location, installation, calibration, and operation of these instruments. The facility should establish procedures, including frequency, for calibration. These instruments, calibration, locations, etc. should meet any local regulatory requirements. For example, US FDA 21 CFR 113 requires calibration at least annually.

7.1 FLOW – TIMING PUMP

7.1.1 Specification

Since product velocity and consequently the residence time are determined by the product flow, the pump used for this purpose is called the “timing” pump. The timing pump is used to limit the maximum flow rate through the holding tube. The pump should be of a positive displacement type. The pump should be designed to effectively limit the amount of product that slips past the pumping elements (rotors or pistons). It should be suitable for exposure to conditions (media, temperature, pressure, etc.) in all phases of operation, including cleaning and sterilization or sanitization.

7.1.2 Location

The timing pump may be located at any point upstream or downstream of the holding tube. The preferred location is upstream of the holding tube. It should not be possible to bypass the timing pump fully or partially. There should not be a tank or other buffer between the flow meter and holding tube that could cause the flow through the holding tube to be different from that through the flow meter.

If product at the flow meter is at a different temperature than at the holding tube, the expected density difference should be included in the sizing calculations (q.v.).

7.1.3 Installation

Timing pumps should be installed as recommended in the manufacturer’s installation manual and to meet any specific regulatory requirements. Pulsation dampers may be used. Pulsation dampers are typically installed with piston type pumps.

7.1.4 Calibration

Maximum timing pump flow should be verified before the first use and periodically thereafter. This can be accomplished using the rate of change in volume in a tank. This can be done using the level change in the system balance tank or at the discharge using a tank or drum (catch tank) with an accurate level or weight measurement. This verification should be done both with and without heating to account for density differences.

Verification of timing pump flow should be done with all other flow promoting or controlling components set to achieve maximum flow through the holding tube – pumps at full speed and valves open.

7.2 Flow – Flow Meter

A flowmeter-based timing system may be used to monitor the flow rate and ensure that the flow rate through the holding tube does not exceed the maximum allowed flow. If so, the flow control device (valve or pump) is controlled by the signal from the flowmeter and may be located either upstream or downstream of the holding tube. A recorder is typically included.

7.2.1 Specification

Flow (timing) meters used to measure the flow rate through the holding tube should have sufficient accuracy and repeatability to ensure that the measured flow rate is correct. The flow meter should be selected based on accuracy in the entire range of potential flow. It should be suitable for exposure to conditions (media, temperature, pressure, etc.) in all phases of operation, including cleaning and sterilization or sanitization.

Flow meters that measure the volumetric flow rate (velocity) directly are preferred. Magnetic flow meters are most used due to their high accuracy. Mass flow meters may be used if the flow measurement, corrected for product density, is as accurate as a volumetric flow meter.

NOTE: Mass flow (Coriolis) meters are not accepted for use in pasteurizers for dairy products under the US Pasteurized Milk Ordinance.

7.2.2 Location

The flow meter may be located at any point upstream or downstream of the holding tube. The preferred location is upstream of the holding tube. It should not be possible to bypass the flow meter fully or partially. There should not be a tank or other buffer between the flow meter and holding tube that could cause the flow through the holding tube to be different from that through the flow meter.

The flow meter should not be located after an injection heater due to the high turbulence (see Installation below).

NOTE: For infusion-based heating, maintenance of a constant level in the infuser should be a critical parameter.

If product at the flow meter is at a different temperature than at the holding tube, the expected density difference should be included in the sizing calculations (see above).

7.2.3 Installation

Flow meters should be installed as recommended in the manufacturer’s installation manual and to meet any specific regulatory requirements. Care should be taken to ensure that the meter is not affected by turbulence caused by the piping or other appurtenances. To avoid air entrapment, the meter should be installed in a vertical or sloping pipe with the flow going up.

7.2.4 Calibration

Flow instrumentation should be calibrated so the transmitter (flow meter) and all receivers (recorder, indicators, PLC/HMI, switches, etc.) read the same value.

Flow meter calibration should be verified before the first use and periodically thereafter. This can be accomplished using the rate of change in volume in a tank. This can be done using the level change in the system balance tank or at the discharge using a tank or drum (catch tank) with an accurate level or weight measurement. This verification should be done both with and without heating to account for density differences.

7.3 Temperature

7.3.1 Specification

Temperature instruments used to measure the temperature in the holding tube should have sufficient accuracy and repeatability to ensure that the measurement is correct. Resistance Temperature Detectors (RTDs) are typically more accurate than thermocouples and are suitable for the temperature ranges normally used in thermal processing. The sensor should be suitable for exposure to conditions (media, temperature, pressure, etc.) in all phases of operation, including cleaning and sterilization or sanitization. It should have sufficient probe length and a reduced tip for faster response and less effect from conduction through the pipe wall.

The transmitter/converter may be included in the sensor head or located elsewhere (e.g., panel mount, PLC input or recorder input).

Dual sensing elements may be used to detect equipment failure or drift. The signals from the two elements are compared and used to alarm if they vary by more than an allowed amount.

7.3.2 Location

The sensing portion of the temperature element should be located to measure the lowest product temperature. This is generally in the center of the product pipe. It is preferred to locate it in a tee or elbow so turbulence will minimize the response time.

The temperature should be measured at the outlet of the holding tube. The end of the holding tube should be taken as the location of the temperature sensor (see Verification section and examples.)

NOTE: Some local regulations require the use of two measurements at the holding tube outlet– one for indication and one connected to a recorder. Associated control can be based on either the indicator or the recorder. (See calibration.)

The temperature may also be measured at the inlet of the holding tube to detect variations in the temperature that could affect the thermal process. This sensor is often also the heater outlet temperature control sensor.

7.3.3 Installation

Temperature sensors should be installed so they can be removed and reach a common point for easy calibration and verification. Temperature sensors can be inserted in a well to allow easy removal and replacement.

7.3.4 Calibration

Temperature instrumentation should be calibrated so the transmitter and all receivers (recorder, indicators, PLC/HMI, switches, etc.) read the same value. Temperature transmitter calibration should be periodically verified using a hot water or oil bath and a thermometer traceable to local/national calibration standards (e.g., the US National Institute of Standards and Technology (NIST)).

NOTE: When two measurements are used at the holding tube outlet, one (typically the indicator) should be calibrated to the standard. The other (typically the recorder and associated controller) may be calibrated to read equal to or lower than the other. US FDA (21 CFR 113, US PMO) requires that the recorder be adjusted to agree as closely as possible with, but in no event higher than, the Temperature Indicating Device.

7.4 Pressure

Pressure in the hold tube is monitored to ensure that flashing has not occurred, changing the liquid volume and the holding time. The pressure should be above the saturated vapor pressure (boiling pressure) of the product at its maximum temperature in the holding tube. The amount above that pressure may be specified by the regulatory agency (e.g., 10 psi by US PMO).

7.4.1 Specification

Pressure instruments used to measure the pressure in the holding tube should have sufficient accuracy and repeatability to ensure that the measurement is correct. The sensor should be suitable for exposure to conditions (media, temperature, pressure, etc.) in all phases of operation, including cleaning and sterilization or sanitization.

7.4.2 Location

The pressure sensor should be located such that it indicates that there is sufficient pressure in the holding tube and final heat exchanger. This is typically located, and may be required by local regulations, at the holding tube outlet (the point of the lowest pressure in the holding tube). However, it can be located after the holding tube if it is before any pumps or valves, and static and dynamic (flow) pressure changes are accounted for in determining the required pressure.

7.4.3 Installation

Pressure sensors should be installed so they can be removed and reach a common point for easy calibration and verification.

7.4.4 Calibration

Pressure instrumentation should be calibrated so the transmitter and all receivers (recorder, indicators, PLC/HMI, switches, etc.) read the same value. Pressure transmitter calibration should be periodically verified using a pressure gauge/indicator traceable to local/national calibration standards (e.g., US NIST)

8 DOCUMENTATION

Documentation for a given holding tube should contain the design calculation(s), construction drawing(s), and configuration drawing(s) in the event of multiple holding tube configurations. Change control should require revision to these documents to reflect any changes to the holding tube.

8.1 DESIGN CALCULATIONS

Design calculation sheets can take one of two forms. The calculation from the manufacturer will start from the fastest particle minimum holding time and calculate the minimum required length. The calculation used as a record to verify the holding tube construction and support the scheduled process will start from the holding tube length measured in the field and calculate the effective holding time for the fastest particle. A separate calculation sheet should be made for each configuration.

The design calculation sheet should show:

- Volume or dimensions to determine volume.
    - This is typically some form of diameter and overall length.
    - Diameter may be inner diameter or the outer diameter along with the thickness.
- Volumetric flow rate.
- All applicable correction factors and basis information. The factors for consideration are listed in the Residence Time Calculation section of this guideline.
- Holding time (required or effective) for the fastest particle.

8.2 CONSTRUCTION DRAWING

The construction drawing should show:

- Isometric view of the holding tube
- Dimensions of all straight lengths
- Dimensions of all bends with equivalent length
- Designed slope
- Location of instrumentation located at or in the holding tube
- If there is only one configuration, the items listed for the configuration drawings as described in the Appendix.

8.3 Configuration Drawings

If multiple configurations are possible, a configuration drawing or view should be supplied for each configuration. For example, one drawing/view depicting the correct configuration for 60 gpm @ 4 s and a separate drawing/view depicting the correct configuration for 90 gpm @ 4 s. Each configuration drawing or view should show:

- Correct connections including applicable swings and monitoring equipment for that configuration.
- Design volumetric flow rate and required holding time for the fastest particle.
- Total length from construction drawing dimensions.
- Optionally:
    - Calculated minimum required length.
    - Fastest particle correction (laminar or turbulent flow) and/or other correction factors.

9 VERIFICATION OF HOLD TUBE

To attain the minimum required holding time it is critical to verify that the construction and installation of the holding tube meets the criteria listed in this Guideline. The purpose of verification is to ensure that design elements that effect the holding time, including some factors outside of the holding tube itself, are met. Specific verification criteria and activities may be required by local regulations.

Note: Verification of the holding tube design and construction does not validate that the holding tube will accomplish its purpose (e.g., microbial reduction, protein denaturization). This guideline does not address validation of holding tubes.

9.1 FREQUENCY:

The holding tube should be verified:

1. Upon installation, typically as part of the Installation Qualification (IQ).
2. Annually thereafter to detect any changes. Any changes should be reviewed and approved through a Change Management program.
3. After any alteration is made which may affect the holding time, including modification of the holding tube or replacement, maintenance or calibration of the timing pump or flow meter.
4. If a flow regime correction other than fully developed laminar flow has been used, the holding time calculation (velocity of the flow and Reynold's Number) should be verified for each new product.
5. After a seal on a speed setting has been broken.
6. Whenever a check of the capacity (i.e., as found testing of the flow meter or pumping rate) indicates a speed up.

9.2 DOCUMENTATION:

- Verify that the flow meter or timing pump flow has been calibrated to the specified parameters.
- Keep a record of all activities carried out and criteria verified during the verification of the hold tube.
- Keep records on file per regulatory requirements or for a period beyond the shelf life of the product, including supporting calculations and calibration certificates for the flow meter, temperature transmitters, recorders, and all other critical instruments.

9.3 Verification Criteria

The following criteria should be considered for verification of a holding tube. The criteria to be verified should be determined for each verification (i.e., initial or follow-up) prior to starting the verification.

9.3.1 General:

- The holding tube sizing calculations (minimum required length) are correct.
- The construction drawings and other design documentation meet the sizing calculations, any filed scheduled process, and other documents. Note that criteria should be verified to meet the criteria listed on a record copy of the construction documents.
- The beginning and end of the holding tube are marked on any drawings used as records of the verification. These points can be marked on the holding tube as a reference.
  - The beginning of the holding tube is typically at the later of a) the start of the upward slope or b) an inlet temperature sensor. For steam injection, the beginning should be after the steam has fully condensed.
  - The end of the holding tube is typically at the earlier of a) the end of the upward slope or b) the indictor or recorder sensor element.

9.3.2 Construction:

- The holding tube diameter conforms to that listed in the calculations, on the construction documents and in any filed scheduled process.
- The material of construction of the holding tube, gaskets, insulation, etc. correspond to the construction drawings and specifications and are suitable for use in all phases of operation, including cleaning and sterilization or sanitization.
- Surface finishes, including welds, meet the specifications and are suitable for hygienic applications.
- Supports for the holding tube are provided to maintain all parts of the holding tubes in a fixed position, free from any lateral or vertical movement other than thermal expansion.
- Heat is not applied to any portion of the holding tube.
- The holding tube is located, or provisions are in place, to prevent excessive or spot cooling such as by material dripping or air blowing on the holding tube.
- Insulation materials can be easily removed for inspection of the holding tube.
- For variable length holding tubes:
  - Each configuration should be verified.
  - Each configuration can be connected without excessive force.
  - When supplied, position detection (proximity switches) indicate that the holding tube is connected correctly. When interlocks through an automated control system are supplied, the interlocks prevent operation if the configuration is not correct.

9.3.3 Slope:

- The holding tube slope is per the construction drawing and other documents.
- The entire hold tube consists of the same diameter.
  - Alternatively, if varying diameter tubing is used, the installation does not trap air AND allows for proper drainage.

9.3.4 Length:

- The length should be measured between the documented beginning and end of the holding tube (see above) and exclude any portion with an incorrect slope (see above).
- One way to measure the holding tube length with fittings (90-degree bends, elbows, etc.) is using a tape measure or a string at the top of the pipe along the centerline. Alternatively, a string or wire inside the holding tube can be used.
- The total length of the holding tube also can be determined by adding the equivalent lengths of the fittings to the measured lengths of straight pipe. The centerline length of the fitting should be treated as an equivalent length of straight pipe. The centerline length may be determined from published fitting dimensions or measured by forming a flexible steel tape or a string along the centerline of the fitting.
- The total length can also be determined by measuring the volume (measure the liquid to fill) and dividing by the inside area.

9.3.5 Direct holding time measurement

- In lieu of measuring the holding tube length, means exist where chemical (e.g., salt) or radiological tracers are injected into the product stream to measure product flow and residence time of the fastest particle. However, these methods are normally not used on a routine basis to verify holding times or product flow rates.
- These methods are typically used for holding times of 15 seconds or more.
- For systems using a timing pump to control (limit) flow, the holding time should be determined in both divert and forward flow.
- The test results, which are based on the flow rate of water, should be converted to the holding time for the products processed.
- An example of this method can be found in the US PMO Appendix I, Test 11.

10 REFERENCES

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11 EXAMPLES

The worksheets used in this document are for example only. Prior to use, all formulas and values should be confirmed by a subject matter expert with experience in holding tube design and construction. Formulas for steam and water physical properties are regressions of steam table data.

11.1 CALCULATIONS

Table 11.1 a, b and c compare the potential differences in holding tube design variety of processes using various assumptions and correction factors. Example calculations (Tables 11.1.1 thru11.1.4) are included for typical conditions. The selection of method and the calculation should be made by a subject matter expert with experience in holding tube design and construction.

In the calculations and tables, the times are based on the following velocities:

- Laminar and turbulent– fastest particle velocity corrections
- Volumetric – average velocity (no flow pattern correction)

Tables 1.1 a-c Comparison tables

a) 100 gpm system nominal flow rate @ 4 seconds, indirect heating, no thermal expansion, flowmeter-based timing [maximum (cut-out) flow rate= 110% of nominal flow rate]

Volumetric	Turbulent	Laminar
262“	315“	524“*

*see Table 1.1.1

b) 100 gpm system nominal rate @ 4 seconds, laminar flow correction, thermal expansion, flowmeter-based timing [maximum (cut-out) flow rate = 110% of nominal flow rate]

Indirect Heating	Direct Heating
556“	622“*

*see Table 1.1.2

c) 100 gpm system nominal flow @ 2 seconds, laminar flow correction, no thermal correction, flowmeter-based timing [maximum (cut-out) flow rate = 110% of nominal flow rate], US PMO Tables & Calculation

Indirect Heating	Direct Heating
262“	294“

see Table 1.1.4

Table 11.1.1 Example Holding Tube Calculation – 100 gpm @ 4 seconds – indirect heating, laminar flow correction

Flowmeter based timing [maximum (cut-out) flow rate = 110% of nominal system flow rate], no product thermal expansion

Hold Tube Size Calculator		Yellow	User Fill
		Grey	Calculated
		Orange	Based on water or standard tubing. Enter actual data if desired.
Tubing Data			
Tube Outside Diameter (inch)		3	Note: Standard sanitary tubing is specified by the outside diameter
Wall Thickness (inch)		0.065	
Fouling Thickness (inch)		0	Optional - Used for flow area calculation
Effective Inside Diameter (in)	D_i	2.870	Note: Tubing OD less wall thickness and fouling
Flow Area (in^2)		6.47	
Flow Input			
Max (Cut-Out) Flow (GPM)	Q_{max}	110	Note: Nominal System flow or higher
Holding Temperature			
Minimum (Cut-Out) Temp (F)	T_{req}	284	
Operating Temp above Minimum (F)		6	
Operating Temp (F)	T	290	
Steam Data			
Steam Pressure at control valve inlet (PSIG)		90	
Steam Temp (F)		331.1	
Steam Latent Heat (BTU/lb)	ΔH_{vap}	886.5	
Direct Heating Correction			
Injector Inlet Temperature (F)		180	
Injector Temperature Rise dT (F)	ΔT	110	
Product Specific Heat (BTU/lb-F)	Cp	1	Note: Use 1.0 for water if not known
Added Condensate (% calc)	CF_{Steam}-1	11.85%	Note: Direct heating will add volume, increasing the flow rate
Added Condensate (% to use)	CF_{Steam}-1	0.00%	Note: Use 0 if indirect heating (no injection or infusion)
Product Density Correction			
Temperature at timing device (F)		250	Note: Temperature at timing pump or flow meter
Specific Gravity at timing device	ρ_{meter}	0.942	
Specific Gravity in holding tube	ρ_{hold}	0.923	
Specific Gravity Correction (calc)	CF_{Therm}	1.021	Note: Accounts for change in volume due to temperature
Specific Gravity Correction (to use)	CF_{Therm}	1	Note: Use 1 for no density correction
Flow Regime Correction			
Corrected Max. Flow Rate (GPM)	Q_{avg}	110.0	Note: Actual flow in holding tube
Average (Volumetric) Velocity (ft/sec)	v_{avg}	5.46	
Product Dynamic Viscosity (cP)	μ	1.00	Note: Viscosity at holding tube temperature
Reynolds Number	Re	111765	
Flow Correction for fastest particle (to use)	$CF_{profile}$	2.0	Note: Flow correction factor is 2 for laminar flow and 1.2 for turbulent
Fastest Particle Velocity (ft/sec)	v_{max}	10.91	

Lethality Residence Time Calculation			
Lethality Reference Temp (F)	T_R	250	
Lethality Temperature Coefficient (F)	z	18	
Target Lethality (minutes)	F	5	
Residence Time required (sec)	t_{req}	3.87	Note: Required holding time for fastest particle.
OPTION 1 - CALCULATE HOLDING TUBE LENGTH			
Residence Time required (sec) (to use)	t_{req}	4.00	
Fastest Particle Velocity			
Minimum Hold Tube Length (ft)	L_{req}	43.65	
Minimum Hold Tube Length (in)	L_{req}	523.7	
Average Velocity			
Minimum Hold Tube Length (ft)	L_{vol}	21.82	
Minimum Hold Tube Length (in)	L_{vol}	261.9	
OPTION 2 - CALCULATE RESIDENCE TIME			
Actual Hold Tube Length (in)	L_{act}	530.0	
Actual Hold Tube Length (ft)	L_{act}	44.2	
Average Residence Time (sec)	t_{avg}	8.10	
Fastest Particle Residence Time (sec)	t_{min}	4.05	
Lethality (minutes)	F	5.22	Note: Based on fastest particle residence time

Table 11.1.2 Example Holding Tube Calculation – 100 gpm @ 4 seconds – direct heating, laminar flow & thermal expansion correction

Flowmeter based timing [maximum (cut-out) flow rate = 110% of nominal system flow rate], product thermal expansion

Hold Tube Size Calculator		Yellow	User Fill
		Grey	Calculated
		Orange	Based on water or standard tubing. Enter actual data if desired.
Tubing Data			
Tube Outside Diameter (inch)		3	Note: Standard sanitary tubing is specified by the outside diameter
Wall Thickness (inch)		0.065	
Fouling Thickness (inch)		0	Optional - Used for flow area calculation
Effective Inside Diameter (in)	D_i	2.870	Note: Tubing OD less wall thickness and fouling
Flow Area (in^2)		6.47	
Flow Input			
Max (Cut-Out) Flow (GPM)	Q_{max}	110	Note: Nominal System flow or higher
Holding Temperature			
Minimum (Cut-Out) Temp (F)	T_{req}	284	
Operating Temp above Minimum (F)		6	
Operating Temp (F)	T	290	
Steam Data			
Steam Pressure at control valve inlet (PSIG)		90	
Steam Temp (F)		331.1	
Steam Latent Heat (BTU/lb)	ΔH_{vap}	886.5	
Direct Heating Correction			
Injector Inlet Temperature (F)		180	
Injector Temperature Rise dT (F)	ΔT	110	
Product Specific Heat (BTU/lb-F)	Cp	1	Note: Use 1.0 for water if not known
Added Condensate (% calc)	$CF_{Steam}-1$	11.85%	Note: Direct heating will add volume, increasing the flow rate
Added Condensate (% to use)	$CF_{Steam}-1$	12.00%	Note: Use 0 if indirect heating (no injection or infusion)
Product Density Correction			
Temperature at timing device (F)		180	Note: Temperature at timing pump or flow meter
Specific Gravity at timing device	ρ_{meter}	0.970	
Specific Gravity in holding tube	ρ_{hold}	0.923	
Specific Gravity Correction (calc)	CF_{Therm}	1.051	Note: Accounts for change in volume due to temperature
Specific Gravity Correction (to use)	CF_{Therm}	1.06	Note: Use 1 for no density correction
Flow Regime Correction			
Corrected Max. Flow Rate (GPM)	Q_{avg}	130.6	Note: Actual flow in holding tube
Average (Volumetric) Velocity (ft/sec)	v_{avg}	6.48	
Product Dynamic Viscosity (cP)	μ	1.00	Note: Viscosity at holding tube temperature
Reynolds Number	Re	132688	
Flow Correction for fastest particle (to use)	$CF_{profile}$	2.0	Note: Flow correction factor is 2 for laminar flow and 1.2 for turbulent
Fastest Particle Velocity (ft/sec)	v_{max}	12.95	

Lethality Residence Time Calculation			
Lethality Reference Temp (F)	T_R	250	
Lethality Temperature Coefficient (F)	z	18	
Target Lethality (minutes)	F	5	
Residence Time required (sec)	t_{req}	3.87	Note: Required holding time for fastest particle.
OPTION 1 - CALCULATE HOLDING TUBE LENGTH			
Residence Time required (sec) (to use)	t_{req}	4.00	
Fastest Particle Velocity			
Minimum Hold Tube Length (ft)	L_{req}	51.82	
Minimum Hold Tube Length (in)	L_{req}	621.8	
Average Velocity			
Minimum Hold Tube Length (ft)	L_{vol}	25.91	
Minimum Hold Tube Length (in)	L_{vol}	310.9	
OPTION 2 - CALCULATE RESIDENCE TIME			
Actual Hold Tube Length (in)	L_{act}	625.0	
Actual Hold Tube Length (ft)	L_{act}	52.1	
Average Residence Time (sec)	t_{avg}	8.04	
Fastest Particle Residence Time (sec)	t_{min}	4.02	
Lethality (minutes)	F	5.19	Note: Based on fastest particle residence time

Table 11.1.3 Example Holding Tube Calculation – 100 gpm @ 15 seconds – indirect heating, volumetric (no) flow correction

Timing pump (no maximum flow adjustment), no product thermal expansion

Hold Tube Size Calculator		Yellow	User Fill
		Grey	Calculated
		Orange	Based on water or standard tubing. Enter actual data if desired.
Tubing Data			
Tube Outside Diameter (inch)		3	Note: Standard sanitary tubing is specified by the outside diameter
Wall Thickness (inch)		0.065	
Fouling Thickness (inch)		0	Optional - Used for flow area calculation
Effective Inside Diameter (in)	D_i	2.870	Note: Tubing OD less wall thickness and fouling
Flow Area (in^2)		6.47	
Flow Input			
Max (Cut-Out) Flow (GPM)	Q_{max}	100	Note: Nominal System flow or higher
Holding Temperature			
Minimum (Cut-Out) Temp (F)	T_{req}	190	
Operating Temp above Minimum (F)		10	
Operating Temp (F)	T	200	
Steam Data			
Steam Pressure at control valve inlet (PSIG)		90	
Steam Temp (F)		331.1	
Steam Latent Heat (BTU/lb)	ΔH_{vap}	886.5	
Direct Heating Correction			
Injector Inlet Temperature (F)		180	
Injector Temperature Rise dT (F)	ΔT	20	
Product Specific Heat (BTU/lb-F)	Cp	1	Note: Use 1.0 for water if not known
Added Condensate (% calc)	CF_{Steam}-1	1.96%	Note: Direct heating will add volume, increasing the flow rate
Added Condensate (% to use)	CF_{Steam}-1	0.00%	Note: Use 0 if indirect heating (no injection or infusion)
Product Density Correction			
Temperature at timing device (F)		70	Note: Temperature at timing pump or flow meter
Specific Gravity at timing device	ρ_{meter}	1.002	
Specific Gravity in holding tube	ρ_{hold}	0.963	
Specific Gravity Correction (calc)	CF_{Therm}	1.041	Note: Accounts for change in volume due to temperature
Specific Gravity Correction (to use)	CF_{Therm}	1	Note: Use 1 for no density correction
Flow Regime Correction			
Corrected Max. Flow Rate (GPM)	Q_{avg}	100.0	Note: Actual flow in holding tube
Average (Volumetric) Velocity (ft/sec)	v_{avg}	4.96	
Product Dynamic Viscosity (cP)	μ	1.00	Note: Viscosity at holding tube temperature
Reynolds Number	Re	106008	
Flow Correction for fastest particle (to use)	$CF_{profile}$	1.0	Note: Flow correction factor is 2 for laminar flow and 1.2 for turbulent
Fastest Particle Velocity (ft/sec)	v_{max}	4.96	

Lethality Residence Time Calculation			
Lethality Reference Temp (F)	T_R	165	
Lethality Temperature Coefficient (F)	z	18	
Target Lethality (minutes)	F	5	
Residence Time required (sec)	t_{req}	12.25	Note: Required holding time for fastest particle.
OPTION 1 - CALCULATE HOLDING TUBE LENGTH			
Residence Time required (sec) (to use)	t_{req}	15.00	
Fastest Particle Velocity			
Minimum Hold Tube Length (ft)	L_{req}	74.40	
Minimum Hold Tube Length (in)	L_{req}	892.7	
Average Velocity			
Minimum Hold Tube Length (ft)	L_{vol}	74.40	
Minimum Hold Tube Length (in)	L_{vol}	892.7	
OPTION 2 - CALCULATE RESIDENCE TIME			
Actual Hold Tube Length (in)	L_{act}	900.0	
Actual Hold Tube Length (ft)	L_{act}	75.0	
Average Residence Time (sec)	t_{avg}	15.12	
Fastest Particle Residence Time (sec)	t_{min}	15.12	
Lethality (minutes)	F	6.17	Note: Based on fastest particle residence time

Table 11.1.4 Example Holding Tube Calculation – 100 gpm @ 2 seconds – US PMO calculation

Flowmeter based timing [maximum (cut-out) flow rate = 110% of nominal system flow rate]

Holding Tube Length Calculator (Based on US PMO)

HHST systems - Holding Time < 15 seconds

Max (Cut-Out) Flow (GPH):	6600	==>	1.8333	GPS
Required Hold Time (sec):	2		110.0	GPM

Indirect Systems (US PMO Appendix I Test 11.3)

	Len / GPS / sec	required length			average velocity
	(PMO table 14)	(inches)	(mm)	gal. / ft.	(fps)
2" Tube	168	616.0	15,646	0.143	12.8
2-1/2" Tube	105	385.0	9,779	0.229	8.0
3" Tube	71.4	261.8	6,650	0.336	5.5

Calculated - Alternate Procedure for non-listed tubing size

Tube Outside Diameter (inch)	3	Note: Standard sanitary tubing is
Inside Diameter (inch)	2.870	Enter ID for non-standard tubing
Required Length (inch)	261.7	
Required Length (mm)	6648.4	
Average Velocity (fps)	5.5	

Direct Systems (US PMO Appendix I Test 11.4)

	Len / GPS / sec	required length			average velocity
	(PMO table 16)	(inches)	(mm)	gal. / ft.	(fps)
2" Tube	188	689.3	17,509	0.143	14.4
2-1/2" Tube	118	432.7	10,990	0.229	9.0
3" Tube	80	293.3	7,451	0.336	6.1

Calculated - Alternate Procedure for non-listed tubing size

Tube Outside Diameter (inch)	3	Note: Standard sanitary tubing is
Inside Diameter (inch)	2.870	Enter ID for non-standard tubing
Required Length (inch)	293.2	
Required Length (mm)	7446.2	
Average Velocity (fps)	6.1	

11.2 HOLDING TUBE DOCUMENTATION EXAMPLES

Drawings with calculations

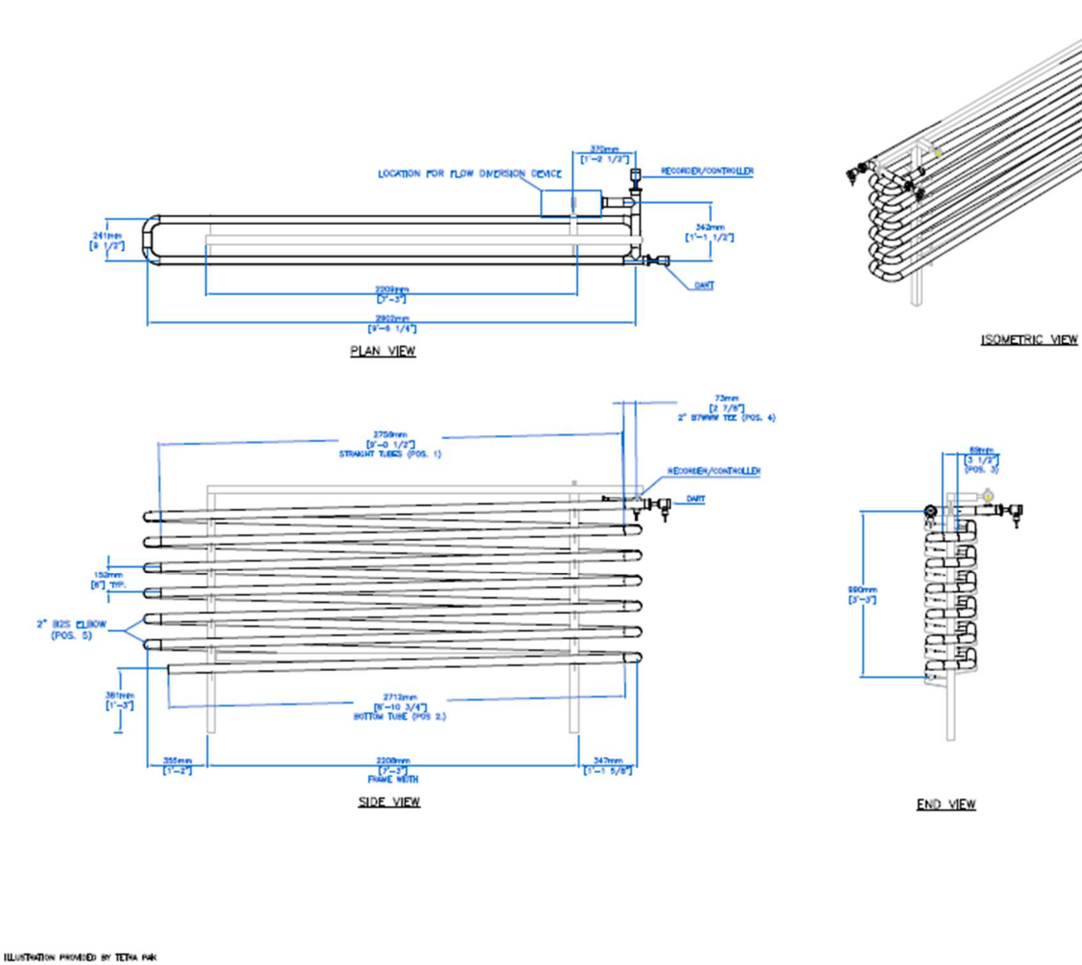
11.2.1 HTST Style

11.2.2 Multiple – Dedicated Style with config views

11.2.3 Multiple – Add-on Style with config views

11.2.4 Spiral Style – non-legal, extended

Figure 11.2.1 HTST Style Holding Tube



HTST PASTEURIZER HOLDING CELL			
HOLDING CELL CONSTRUCTION DRAWING			
System Nominal Flow		3600	GPH
Holding Cell Design Flow		3960	GPH
Required Holding Time		15	sec
Required Holding Cell Length		1582	inch
Required Holding Cell Slope		1/4	inch per foot
Pos.	**Calculated Length**	**Item Qty**	**Length ea. (inch)**
1	Tube 50.8" x .065"	12	108.5
2	Tube 50.8" x .065"	1	106.75
3	Tube 50.8" x .065"	12	3.5
4	Tee Pipe B7WWW 2"	1	2.875
5	Pipe Bend 90 B2S W 2"	24	6.83
Total Holding Cell Length			
1617.5 inch			

HTST PASTEURIZER HOLDING CELL
HOLDING CELL CONSTRUCTION DRAWING

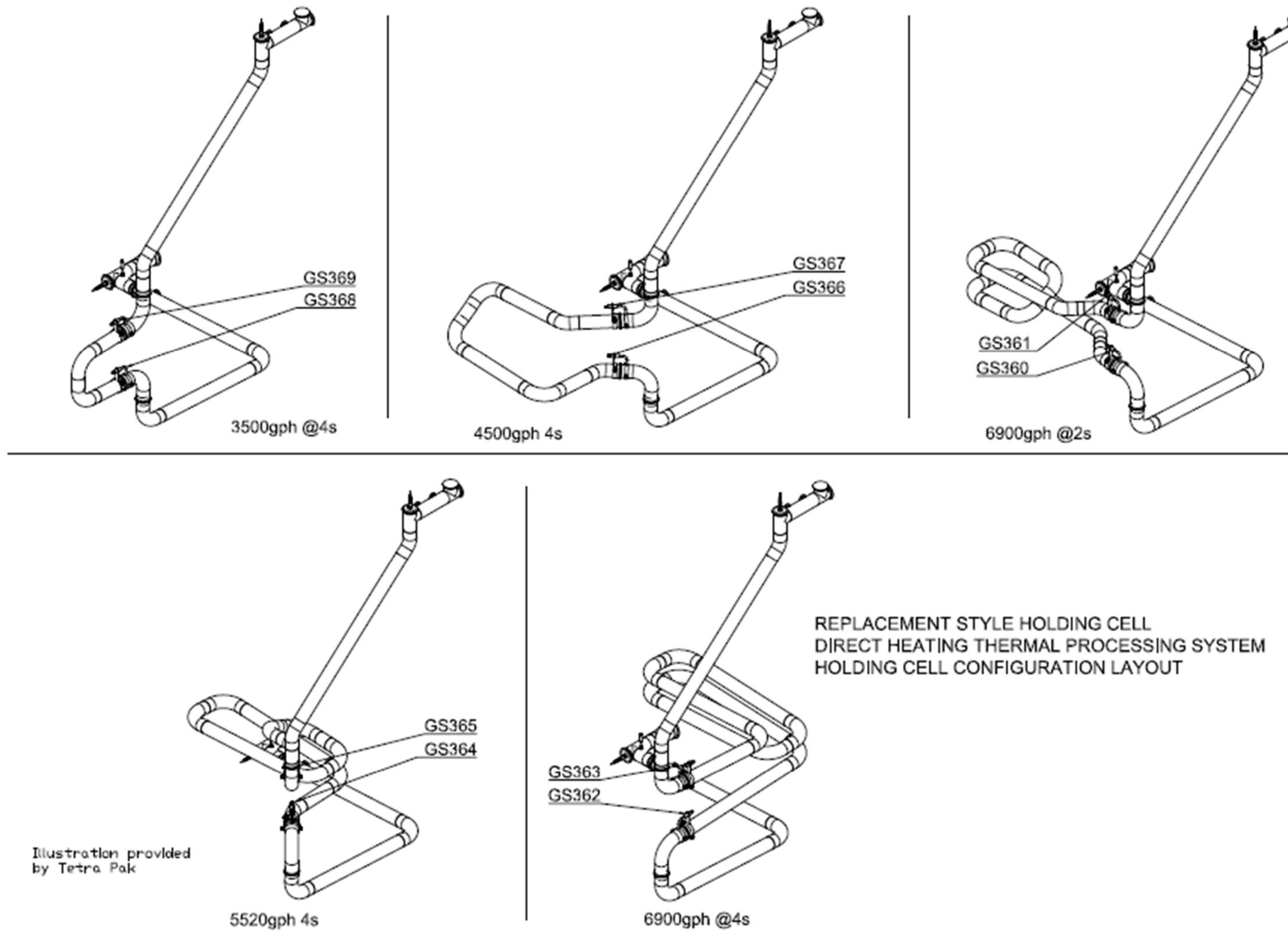
Holding Tube Length Calculator (Based on PMO)

HTST systems - Holding Time = 15 seconds or greater (PMO Appendix I Test 11.1 or 11.2a)

Max (Cut-Out) Flow (GPH):	3960	==>	1.1000	GPS
Required Hold Time (sec):	15		66.0	GPM
Factor	14.00%	Note: 14% recommended by 3-A Accepted Practice		

Tube Outside Diameter (inch)	2	Note: Standard sanitary tubing is specified by the outside di
Inside Diameter (inch)	1.870	Enter ID for non-standard tubing
Required Length (inch)	1582.0	
Required Length (mm)	40182.3	
Average Velocity (fps)	8.6	

Figure 11.2.2 Multiple Holding Tubes – Dedicated Style Holding Tube with config views



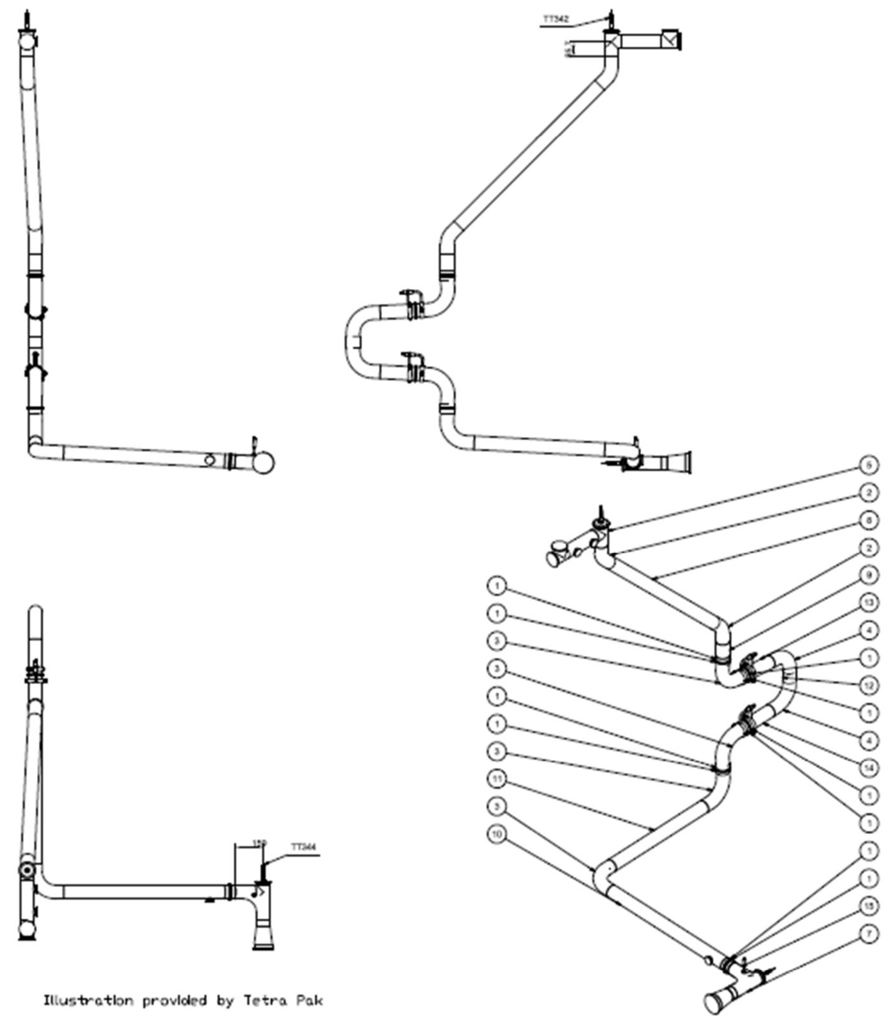


Illustration provided by Tetra Pak

Notes:
All tubing is designed at a 3' slope unless otherwise noted

All Dimensions are in millimeters unless otherwise noted

Nominal system flow: 3500 GPH
Maximum cutout flow: 65 GPM
Minimum residence time: 4,0 seconds
Turbulent flow profile calculation
Minimum calculated length; 220,5" ≈ 5600mm

HOLDING CELL CALCULATION			
Pos.	ITEM QTY	Description	Length
		Total Design Length	[illegible]
15	1	Tube 76,2 x 1,6 mm, [illegible]	116
14	1	Tube 76,2 x 1,6 mm, [illegible]	170
13	1	Tube 76,2 x 1,6 mm, [illegible]	170
12	1	Tube 76,2 x 1,6 mm, [illegible]	65
11	1	Tube 76,2 x 1,6 mm, [illegible]	734
10	1	Tube 76,2 x 1,6 mm, [illegible]	906
9	1	Tube 76,2 x 1,6 mm, [illegible]	95
8	1	Tube 76,2 x 1,6 mm, [illegible]	1118
7	1	Tube 76,2 x 1,6 mm, [illegible]	42
6	2	[illegible]	[illegible]
4	2	Cut Pipe bend 3A 90 B25 W 316L 3"	238
3	4	Pipe bend 3A 90 B25 W 316L 3"	[illegible]
2	2	Pipe bend 3A 45 B2XS W 316L 3"	[illegible]
1	10	[illegible]	[illegible]

REPLACMENT HOLDING CELL
DIRECT HEATING THERMAL PROCESSING SYSTEM
HOLDING CELL CONSTRUCTION LAYOUT
3500 GPH @ 4 SECONDS

Hold Tube Size Calculator	Yellow	User Fill
	Grey	Calculated
	Orange	Based on water or standard tubing. Enter actual data if desired.
Tubing Data		
Tube Outside Diameter (inch)	3	Note: Standard sanitary tubing is specified by the outside diameter
Wall Thickness (inch)	0.065	
Fouling Thickness (inch)	0	Optional - Used for flow area calculation
Effective Inside Diameter (in)	2.870	Note: Tubing OD less wall thickness and fouling
Flow Area (in^2)	6.47	
Flow Input		
Max (Cut-Out) Flow (GPM)	65	Note: Nominal System flow or higher
Holding Temperature		
Minimum (Cut-Out) Temp (F)	284	
Operating Temp above Minimum (F)	6	
Operating Temp (F)	290	
Steam Data		
Steam Pressure at control valve inlet (PSIG)	80	
Steam Temp (F)	323.0	
Steam Latent Heat (BTU/lb)	892.7	
Direct Heating Correction		
Injector Inlet Temperature (F)	180	
Injector Temperature Rise dT (F)	110	
Product Specific Heat (BTU/lb-F)	1	Note: Use 1.0 for water if not known
Added Condensate (% calc)	11.87%	Note: Direct heating will add volume, increasing the flow rate
Added Condensate (% to use)	12.00%	Note: Use 0 if indirect heating (no injection or infusion)
Product Density Correction		
Temperature at timing device (F)	180	Note: Temperature at timing pump or flow meter
Specific Gravity at timing device	0.970	
Specific Gravity in holding tube	0.923	
Specific Gravity Correction (calc)	1.051	Note: Accounts for change in volume due to temperature
Specific Gravity Correction (to use)	1.06	Note: Use 1 for no density correction
Flow Regime Correction		
Corrected Max. Flow Rate (GPM)	77.2	Note: Actual flow in holding tube
Average (Volumetric) Velocity (ft/sec)	3.83	
Product Dynamic Viscosity (cP)	1.00	Note: Viscosity at holding tube temperature
Reynolds Number (Re)	78406.50	
Flow Correction for fastest particle (to use)	1.2	Note: Flow correction factor is 2 for laminar flow and 1.2 for turbulent
Fastest Particle Velocity (ft/sec)	4.59	
Lethality Residence Time Calculation		
Lethality Reference Temp (F)	250	
Lethality z-value (F)	18	
Target Lethality - F (minutes)	5	
Residence Time required (sec)	3.87	Note: Required holding time for fastest particle.
OPTION 1 - CALCULATE HOLDING TUBE LENGTH		
Residence Time required (sec) (to use)	4.00	
Fastest Particle Velocity		
Minimum Hold Tube Length (ft)	18.4	
Minimum Hold Tube Length (in)	220.5	5599.502123
Average Velocity		
Minimum Hold Tube Length (ft)	15.3	
Minimum Hold Tube Length (in)	183.7	
OPTION 2 - CALCULATE RESIDENCE TIME		
Actual Hold Tube Length (in)	224.4	
Actual Hold Tube Length (ft)	18.7	
Average Residence Time (sec)	4.89	
Fastest Particle Residence Time (sec)	4.07	
Lethality - F (minutes)	5.25	Note: Based on fastest particle residence time

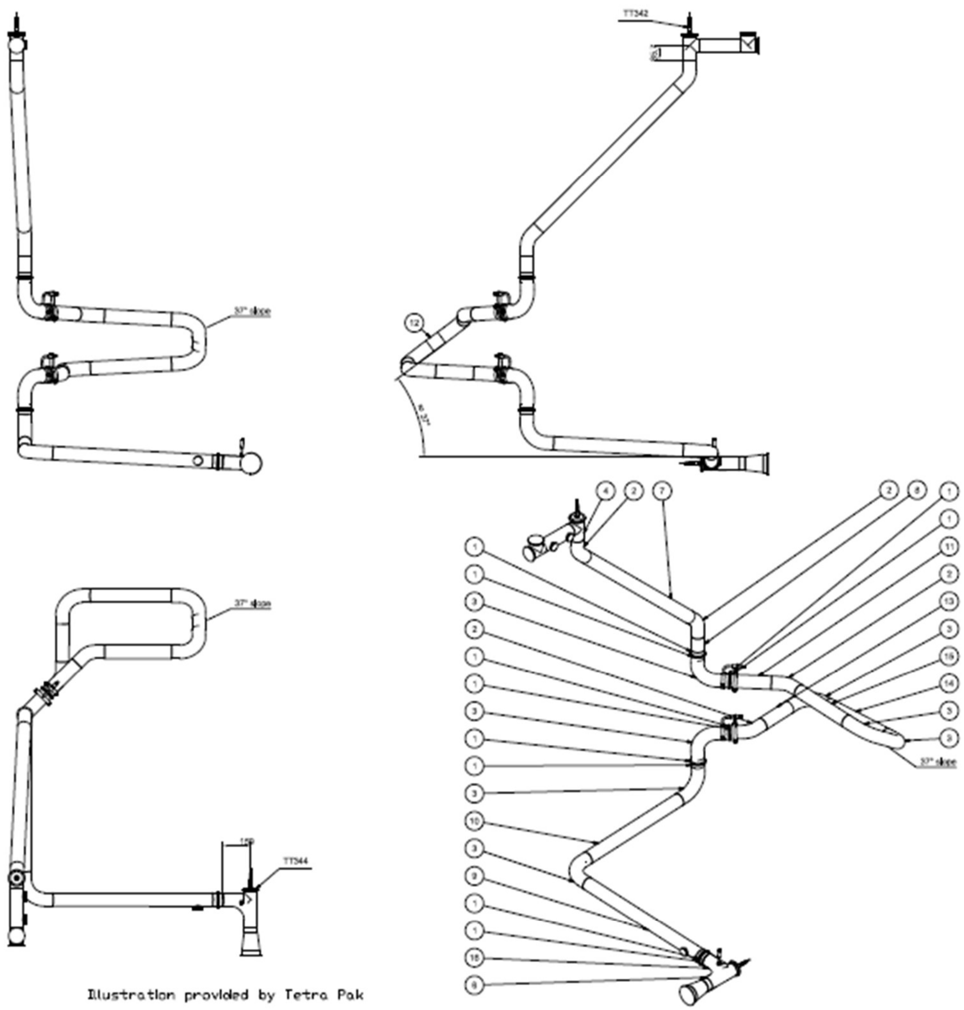


Illustration provided by Tetra Pak

Notes:
All tubing is designed at a 3° slopes

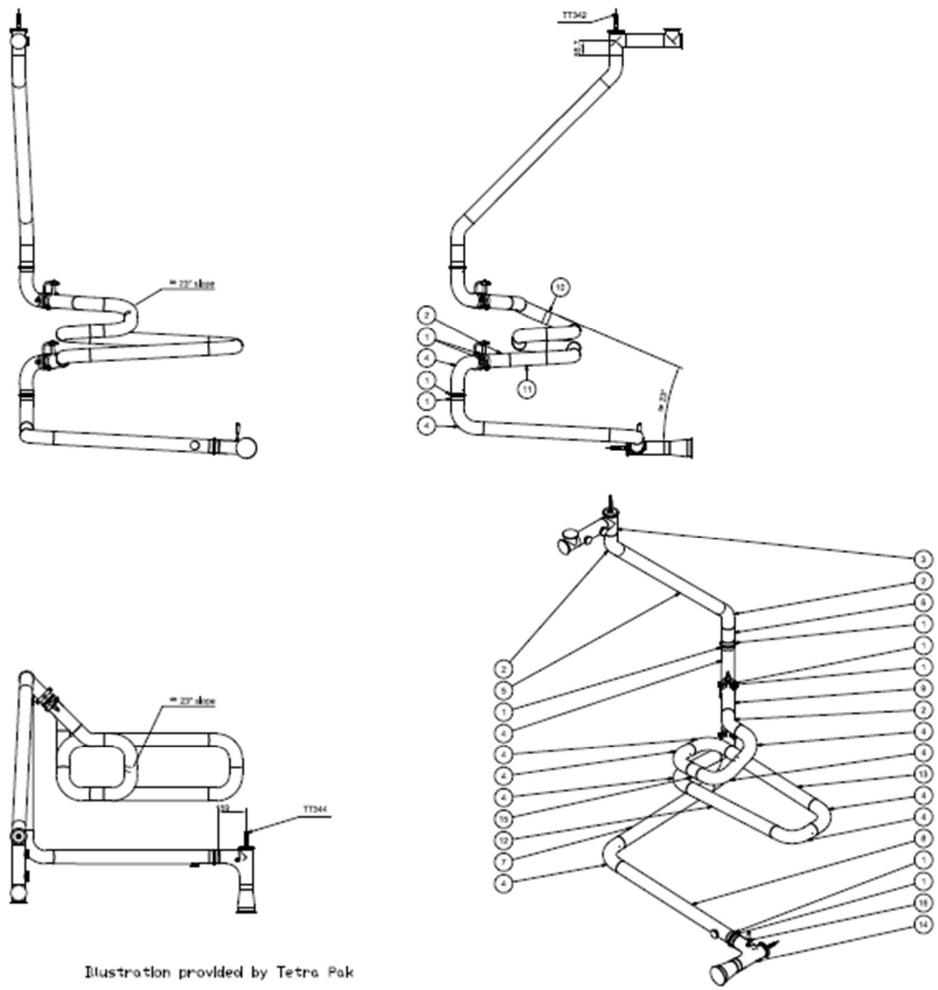
All Dimensions are in millimeters
unless otherwise noted

Nominal system flow: 4500 GPH
Maximum cutout flow: 83 GPM
Minimum residence time: 4.0 seconds
Turbulent flow profile calculation
Minimum calculated length: 281.5" = 7151mm

HOLDING CELL CALCULATION			
Pos.	ITEM QTY	Description	Length
		Total Design Length	7324,7
16	1	Tube 76,2 x 1,6 mm, [illegible]	116
15	1	Tube 76,2 x 1,6 mm, [illegible]	380
14	1	Tube 76,2 x 1,6 mm, [illegible]	480
13	1	Tube 76,2 x 1,6 mm, [illegible]	214
12	1	Tube 76,2 x 1,6 mm, [illegible]	82
11	1	Tube 76,2 x 1,6 mm, [illegible]	288
10	1	Tube 76,2 x 1,6 mm, [illegible]	734
9	1	Tube 76,2 x 1,6 mm, [illegible]	[illegible]
8	1	Tube 76,2 x 1,6 mm, [illegible]	98
7	1	Tube 76,2 x 1,6 mm, [illegible]	1118
6	1	Tube 76,2 x 1,6 mm, [illegible]	42
4	2	[illegible]	[illegible]
3	7	Pipe bend 3A 90 [illegible] 316L 3"	[illegible]
2	4	Pipe bend 3A 45 [illegible] 316L 3"	180
1	10	[illegible] 3"	[illegible]

REPLACMENT HOLDING CELL
DIRECT HEATING THERMAL PROCESSING SYSTEM
HOLDING CELL CONSTRUCTION LAYOUT
4500 GPH @ 4 SECONDS

Hold Tube Size Calculator	Yellow	User Fill
	Grey	Calculated
	Orange	Based on water or standard tubing. Enter actual data if desired.
Tubing Data		
Tube Outside Diameter (inch)	3	Note: Standard sanitary tubing is specified by the outside diameter
Wall Thickness (inch)	0.065	
Fouling Thickness (inch)	0	Optional - Used for flow area calculation
Effective Inside Diameter (in)	2.870	Note: Tubing OD less wall thickness and fouling
Flow Area (in^2)	6.47	
Flow Input		
Max (Cut-Out) Flow (GPM)	83	Note: Nominal System flow or higher
Holding Temperature		
Minimum (Cut-Out) Temp (F)	284	
Operating Temp above Minimum (F)	6	
Operating Temp (F)	290	
Steam Data		
Steam Pressure at control valve inlet (PSIG)	80	
Steam Temp (F)	323.0	
Steam Latent Heat (BTU/lb)	892.7	
Direct Heating Correction		
Injector Inlet Temperature (F)	180	
Injector Temperature Rise dT (F)	110	
Product Specific Heat (BTU/lb-F)	1	Note: Use 1.0 for water if not known
Added Condensate (% calc)	11.87%	Note: Direct heating will add volume, increasing the flow rate
Added Condensate (% to use)	12.00%	Note: Use 0 if indirect heating (no injection or infusion)
Product Density Correction		
Temperature at timing device (F)	180	Note: Temperature at timing pump or flow meter
Specific Gravity at timing device	0.970	
Specific Gravity in holding tube	0.923	
Specific Gravity Correction (calc)	1.051	Note: Accounts for change in volume due to temperature
Specific Gravity Correction (to use)	1.06	Note: Use 1 for no density correction
Flow Regime Correction		
Corrected Max. Flow Rate (GPM)	98.5	Note: Actual flow in holding tube
Average (Volumetric) Velocity (ft/sec)	4.89	
Product Dynamic Viscosity (cP)	1.00	Note: Viscosity at holding tube temperature
Reynolds Number (Re)	100119.07	
Flow Correction for fastest particle (to use)	1.2	Note: Flow correction factor is 2 for laminar flow and 1.2 for turbulent
Fastest Particle Velocity (ft/sec)	5.86	
Lethality Residence Time Calculation		
Lethality Reference Temp (F)	250	
Lethality z-value (F)	18	
Target Lethality - F (minutes)	5	
Residence Time required (sec)	3.87	Note: Required holding time for fastest particle
OPTION 1 - CALCULATE HOLDING TUBE LENGTH		
Residence Time required (sec) (to use)	4.00	
Fastest Particle Velocity		
Minimum Hold Tube Length (ft)	23.5	
Minimum Hold Tube Length (in)	281.5	7150.13348
Average Velocity		
Minimum Hold Tube Length (ft)	19.5	
Minimum Hold Tube Length (in)	234.6	
OPTION 2 - CALCULATE RESIDENCE TIME		
Actual Hold Tube Length (in)	288.4	
Actual Hold Tube Length (ft)	24.0	
Average Residence Time (sec)	4.92	
Fastest Particle Residence Time (sec)	4.10	
Lethality - F (minutes)	5.29	Note: Based on fastest particle residence time



Notes:
All tubing is designed at a 3° slopes

All Dimensions are in millimeters
unless otherwise noted

Nominal system flow: 5520 GPH
Maximum cutout flow: 102 GPM
Minimum residence time: 4,0 seconds
Turbulent flow profile calculation
Minimum calculated length: 345,9" = 8787 mm

HOLDING CELL CALCULATION			
Pos.	ITEM QTY	Description	Length
		Total Design Length	[illegible]
16	1	Tube 76,2 x 1,6 mm, [illegible]	116
15	1	Tube 76,2 x 1,6 mm, [illegible]	51
14	1	Tube 76,2 x 1,6 mm, [illegible]	52
13	1	Tube 76,2 x 1,6 mm, [illegible]	692
12	1	Tube 76,2 x 1,6 mm, [illegible]	692
11	1	Tube 76,2 x 1,6 mm, [illegible]	214
10	1	Tube 76,2 x 1,6 mm, [illegible]	33
9	1	Tube 76,2 x 1,6 mm, [illegible]	238
8	1	Tube 76,2 x 1,6 mm, [illegible]	506
7	1	Tube 76,2 x 1,6 mm, [illegible]	734
6	1	Tube 76,2 x 1,6 mm, [illegible]	89
5	1	Tube 76,2 x 1,6 mm, [illegible]	1118
4	11	Pipe bend 3A 90 [illegible] 316L 3"	298
3	1	[illegible]	65,7
2	4	Pipe bend 3A 45 [illegible] 316L 3"	180
1	10	Ferrule [illegible] 316L 3"	28,6

REPLACMENT HOLDING CELL
DIRECT HEATING THERMAL PROCESSING SYSTEM
HOLDING CELL CONSTRUCTION LAYOUT
5520 GPH @ 4 SECONDS

Illustration provided by Tetra Pak

Hold Tube Size Calculator	Yellow	User Fill
	Grey	Calculated
	Orange	Based on water or standard tubing. Enter actual data if desired.
Tubing Data		
Tube Outside Diameter (inch)	3	Note: Standard sanitary tubing is specified by the outside diameter
Wall Thickness (inch)	0.065	
Fouling Thickness (inch)	0	Optional - Used for flow area calculation
Effective Inside Diameter (in)	2.870	Note: Tubing OD less wall thickness and fouling
Flow Area (in^2)	6.47	
Flow Input		
Max (Cut-Out) Flow (GPM)	102	Note: Nominal System flow or higher
Holding Temperature		
Minimum (Cut-Out) Temp (F)	284	
Operating Temp above Minimum (F)	6	
Operating Temp (F)	290	
Steam Data		
Steam Pressure at control valve inlet (PSIG)	80	
Steam Temp (F)	323.0	
Steam Latent Heat (BTU/lb)	892.7	
Direct Heating Correction		
Injector Inlet Temperature (F)	180	
Injector Temperature Rise dT (F)	110	
Product Specific Heat (BTU/lb-F)	1	Note: Use 1.0 for water if not known
Added Condensate (% calc)	11.87%	Note: Direct heating will add volume, increasing the flow rate
Added Condensate (% to use)	12.00%	Note: Use 0 if indirect heating (no injection or infusion)
Product Density Correction		
Temperature at timing device (F)	180	Note: Temperature at timing pump or flow meter
Specific Gravity at timing device	0.970	
Specific Gravity in holding tube	0.923	
Specific Gravity Correction (calc)	1.051	Note: Accounts for change in volume due to temperature
Specific Gravity Correction (to use)	1.05	Note: Use 1 for no density correction
Flow Regime Correction		
Corrected Max. Flow Rate (GPM)	121.1	Note: Actual flow in holding tube
Average (Volumetric) Velocity (ft/sec)	6.01	
Product Dynamic Viscosity (cP)	1.00	Note: Viscosity at holding tube temperature
Reynolds Number (Re)	123037.89	
Flow Correction for fastest particle (to use)	1.2	Note: Flow correction factor is 2 for laminar flow and 1.2 for turbulent
Fastest Particle Velocity (ft/sec)	7.21	
Lethality Residence Time Calculation		
Lethality Reference Temp (F)	250	
Lethality z-value (F)	18	
Target Lethality - F (minutes)	5	
Residence Time required (sec)	3.87	Note: Required holding time for fastest particle
OPTION 1 - CALCULATE HOLDING TUBE LENGTH		
Residence Time required (sec) (to use)	4.00	
Fastest Particle Velocity		
Minimum Hold Tube Length (ft)	28.8	
Minimum Hold Tube Length (in)	345.9	8786.911024
Average Velocity		
Minimum Hold Tube Length (ft)	24.0	
Minimum Hold Tube Length (in)	288.3	
OPTION 2 - CALCULATE RESIDENCE TIME		
Actual Hold Tube Length (in)	353.1	
Actual Hold Tube Length (ft)	29.4	
Average Residence Time (sec)	4.90	
Fastest Particle Residence Time (sec)	4.08	
Lethality - F (minutes)	5.27	Note: Based on fastest particle residence time

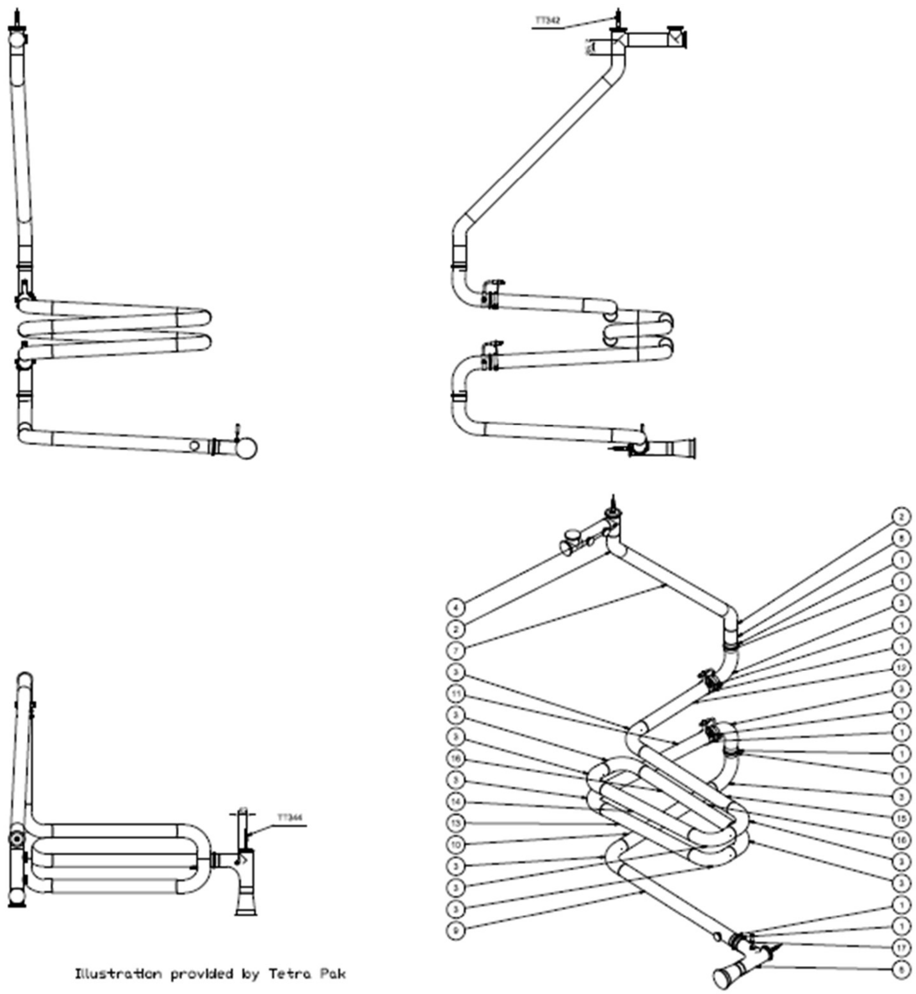


Illustration provided by Tetra Pak

Notes:
All tubing is designed at a 3° slopes

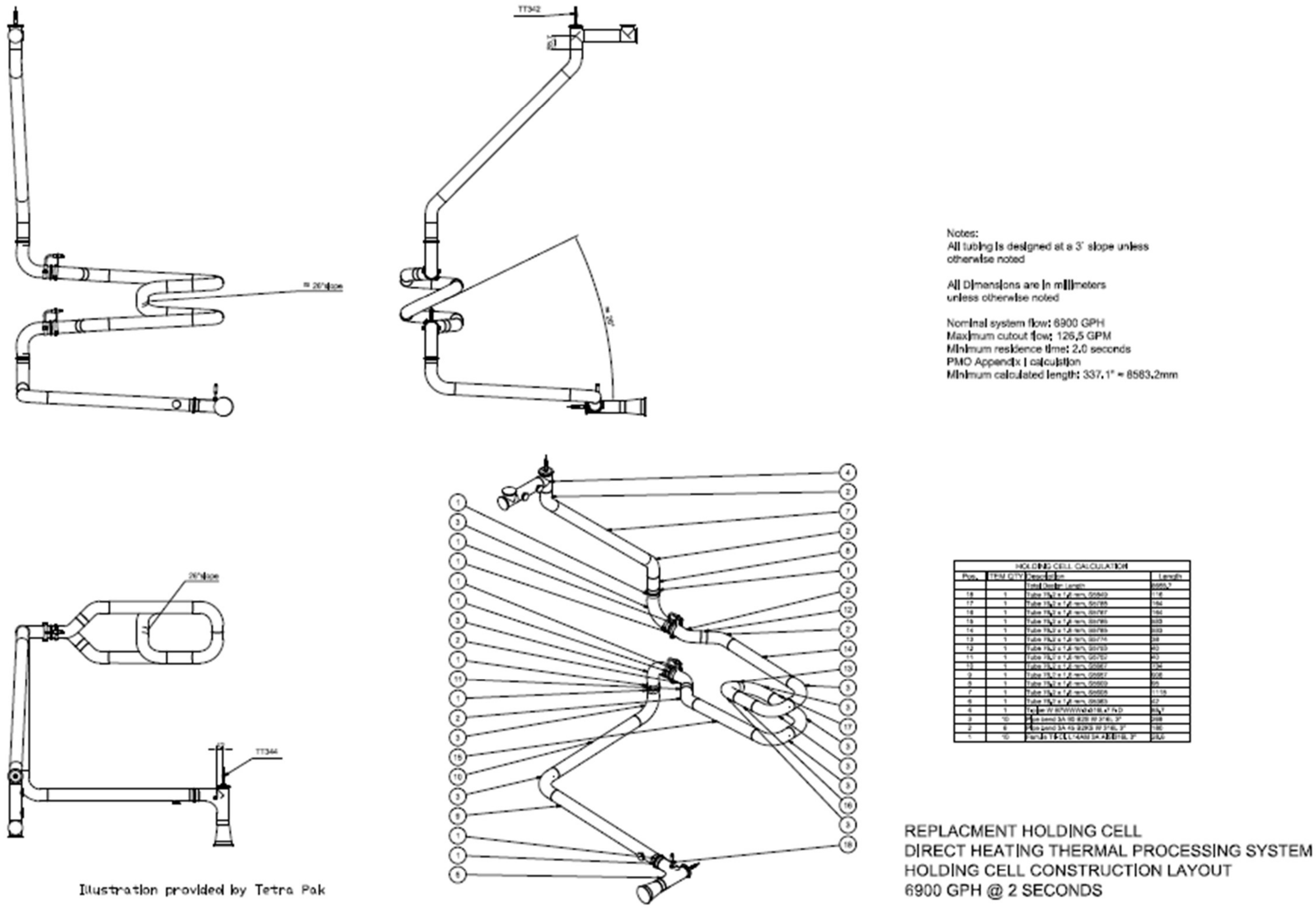
All Dimensions are in millimeters
unless otherwise noted

Nominal system flow: 6900 GPH
Maximum cutout flow: 127 GPM
Minimum residence time: 4,0 seconds
Turbulent flow profile calculation
Minimum calculated length: 430,7" = 10941 mm

HOLDING CELL CALCULATION			
Pos.	ITEM QTY	Description	Length
18		Total Design Length	11182,7
17	1	Tube 76,2 x 1,6 mm, [illegible]	116
16	1	Tube 76,2 x 1,6 mm, [illegible]	731
15	1	Tube 76,2 x 1,6 mm, [illegible]	731
14	1	Tube 76,2 x 1,6 mm, [illegible]	731
13	1	Tube 76,2 x 1,6 mm, [illegible]	731
12	1	Tube 76,2 x 1,6 mm, [illegible]	910
11	1	Tube 76,2 x 1,6 mm, [illegible]	882
10	1	Tube 76,2 x 1,6 mm, [illegible]	734
9	1	Tube 76,2 x 1,6 mm, [illegible]	809
8	1	Tube 76,2 x 1,6 mm, [illegible]	95
7	1	Tube 76,2 x 1,6 mm, [illegible]	1116
6	1	Tube 76,2 x 1,6 mm, [illegible]	42
4	1	[illegible]	85,7
3	12	Pipe bend 3A 90 [illegible] 316L 3"	268
2	2	Pipe bend 3A 45 [illegible] 316L 3"	180
1	10	Ferrule [illegible] 316L 3"	28,3

REPLACMENT HOLDING CELL
DIRECT HEATING THERMAL PROCESSING SYSTEM
HOLDING CELL CONSTRUCTION LAYOUT
6900 GPH @ 4 SECONDS

Hold Tube Size Calculator	Yellow	User Fill
	Grey	Calculated
	Orange	Based on water or standard tubing. Enter actual data if desired.
Tubing Data		
Tube Outside Diameter (inch)	3	Note: Standard sanitary tubing is specified by the outside diameter
Wall Thickness (inch)	0.065	
Fouling Thickness (inch)	0	Optional - Used for flow area calculation
Effective Inside Diameter (in)	2.870	Note: Tubing OD less wall thickness and fouling
Flow Area (in^2)	6.47	
Flow Input		
Max (Cut-Out) Flow (GPM)	127	Note: Nominal System flow or higher
Holding Temperature		
Minimum (Cut-Out) Temp (F)	284	
Operating Temp above Minimum (F)	6	
Operating Temp (F)	290	
Steam Data		
Steam Pressure at control valve inlet (PSIG)	80	
Steam Temp (F)	323.0	
Steam Latent Heat (BTU/lb)	892.7	
Direct Heating Correction		
Injector Inlet Temperature (F)	180	
Injector Temperature Rise dT (F)	110	
Product Specific Heat (BTU/lb-F)	1	Note: Use 1.0 for water if not known
Added Condensate (% calc)	11.87%	Note: Direct heating will add volume, increasing the flow rate
Added Condensate (% to use)	12.00%	Note: Use 0 if indirect heating (no injection or infusion)
Product Density Correction		
Temperature at timing device (F)	180	Note: Temperature at timing pump or flow meter
Specific Gravity at timing device	0.970	
Specific Gravity in holding tube	0.923	
Specific Gravity Correction (calc)	1.051	Note: Accounts for change in volume due to temperature
Specific Gravity Correction (to use)	1.06	Note: Use 1 for no density correction
Flow Regime Correction		
Corrected Max. Flow Rate (GPM)	150.8	Note: Actual flow in holding tube
Average (Volumetric) Velocity (ft/sec)	7.48	
Product Dynamic Viscosity (cP)	1.00	Note: Viscosity at holding tube temperature
Reynolds Number (Re)	153194.24	
Flow Correction for fastest particle (to use)	1.2	Note: Flow correction factor is 2 for laminar flow and 1.2 for turbulent
Fastest Particle Velocity (ft/sec)	8.97	
Lethality Residence Time Calculation		
Lethality Reference Temp (F)	250	
Lethality z-value (F)	18	
Target Lethality - F (minutes)	5	
Residence Time required (sec)	3.87	Note: Required holding time for fastest particle.
OPTION 1 - CALCULATE HOLDING TUBE LENGTH		
Residence Time required (sec) (to use)	4.00	
Fastest Particle Velocity		
Minimum Hold Tube Length (ft)	35.9	
Minimum Hold Tube Length (in)	430.7	10940.56569
Average Velocity		GPM
Minimum Hold Tube Length (ft)	29.9	
Minimum Hold Tube Length (in)	358.9	
OPTION 2 - CALCULATE RESIDENCE TIME		
Actual Hold Tube Length (in)	440.3	
Actual Hold Tube Length (ft)	36.7	
Average Residence Time (sec)	4.91	
Fastest Particle Residence Time (sec)	4.09	
Lethality - F (minutes)	5.28	Note: Based on fastest particle residence time



Pos.	TPM QTY	Description	Length
		Total Design Length	[illegible]
18	1	Tube [illegible]	116
17	1	Tube [illegible]	164
16	1	Tube [illegible]	164
15	1	Tube [illegible]	333
14	1	Tube [illegible]	333
13	1	Tube [illegible]	38
12	1	Tube [illegible]	40
11	1	Tube [illegible]	40
10	1	Tube [illegible]	[illegible]
9	1	Tube [illegible]	[illegible]
8	1	Tube [illegible]	[illegible]
7	1	Tube [illegible]	1118
6	1	Tube [illegible]	[illegible]
4	1	[illegible]	[illegible]
3	10	Pipe bend [illegible]	[illegible]
2	6	Pipe bend [illegible]	180
1	10	[illegible]	[illegible]

Illustration provided by Tetra Pak

Holding Tube Length Calculator (Based on PMO)

HHST systems - Holding Time < 15 seconds

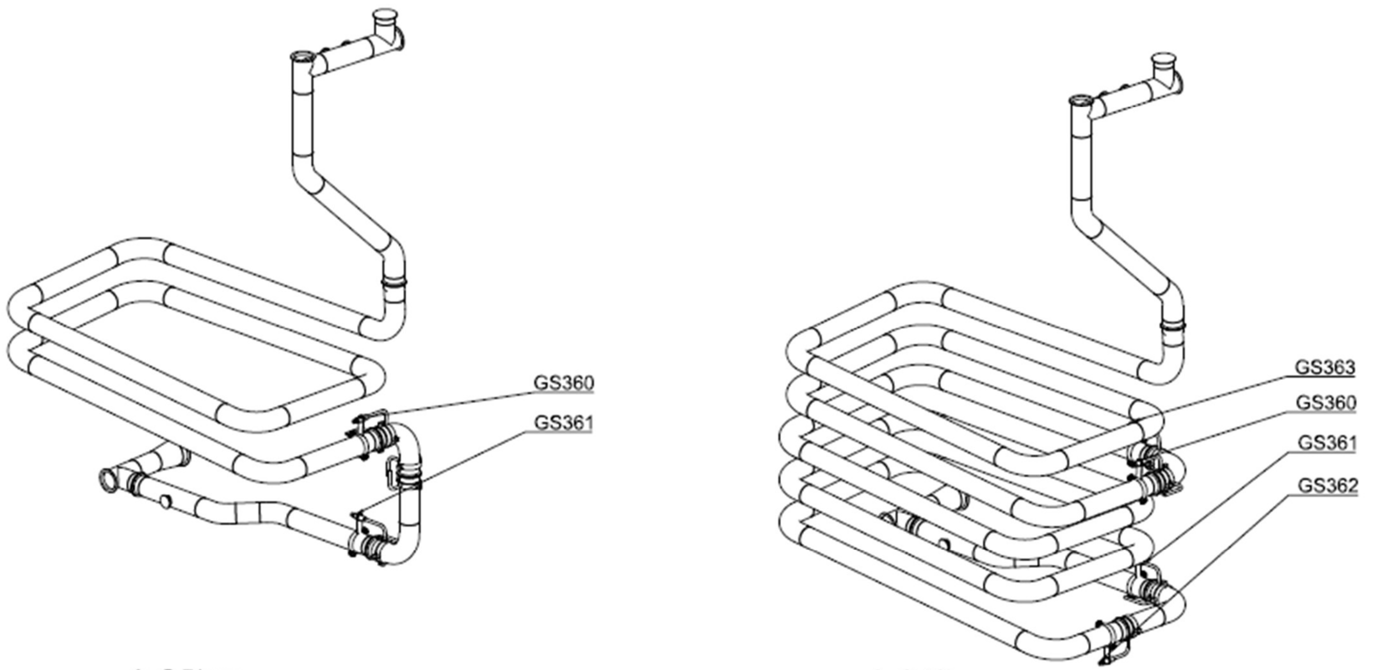
Max (Cut-Out) Flow (GPH):	7590	==>	2.1083	GPS
Required Hold Time (sec):	2		126.5	GPM

	Direct Systems (PMO Appendix I Test 11.4)				
	Len / GPS / sec	required length			average velocity
	(PMO table 16)	(inches)	(mm)	gal. / ft.	(fps)
2" Tube	188	792.7	20,135	0.143	16.5
2-1/2" Tube	118	497.6	12,638	0.229	10.3
3" Tube	80	337.3	8,568	0.336	7.0

Calculated - Alternate Procedure for non-listed tubing size

Tube Outside Diameter (inch)	3	Note: Standard sanitary tubing is specified by the outside diameter
Inside Diameter (inch)	2.870	Enter ID for non-standard tubing
Required Length (inch)	337.1	
Required Length (mm)	8563.2	
Average Velocity (fps)	7.0	

Figure 11.2.4 Multiple Holding Tubes – Add-on Style with config views

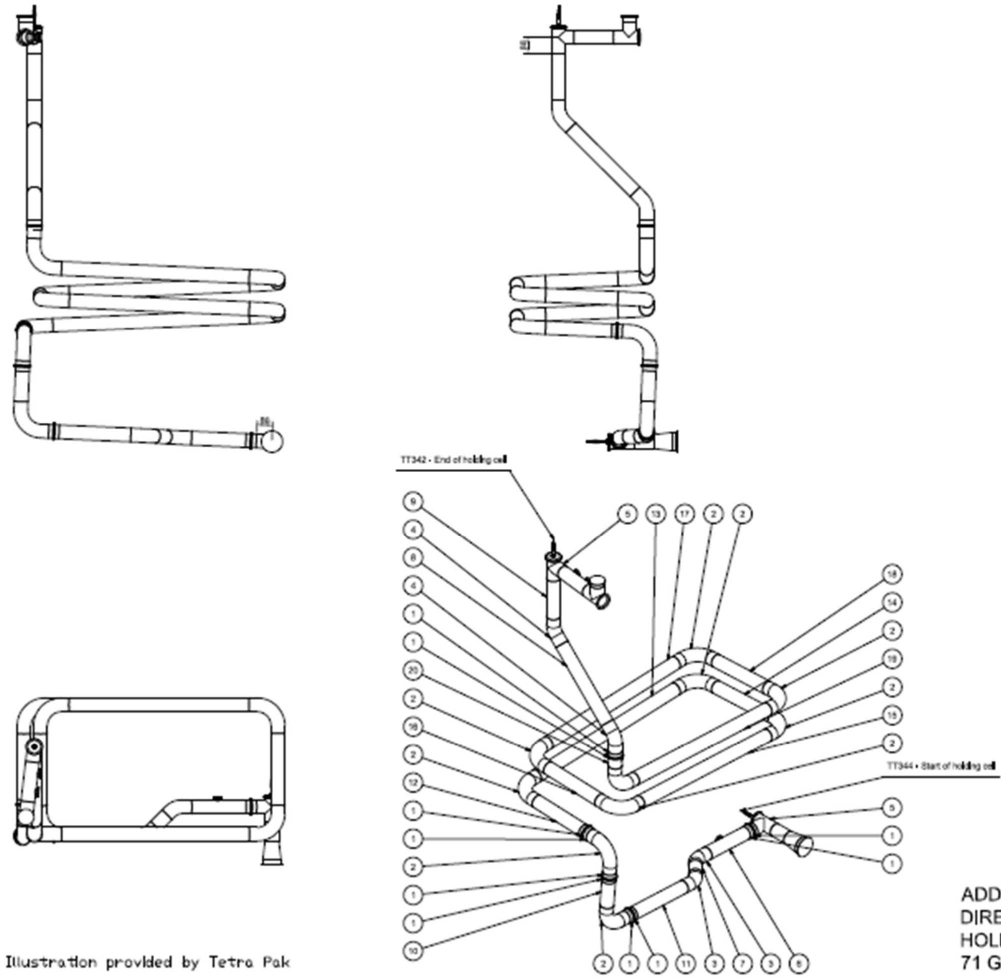


4s @ 71gpm

4s @ 143gpm

Illustration provided by Tetra Pak

ADD-ON HOLDING CELL
DIRECT HEATING THERMAL PROCESSING SYSTEM
HOLDING CELL CONFIGURATION LAYOUT



Notes:
All tubing is designed at a 2.5° slope
unless otherwise dimensioned

All Dimensions are in millimeters
unless otherwise noted

Nominal system flow: 71 GPM
Maximum cutout flow: 78.1 GPM
Minimum residence time: 4,0 seconds
Laminar flow profile correction
Minimum calculated length: 441.5" = 11214mm

HOLDING CELL CALCULATION			
Pos.	ITEM QTY	Description	Length
		Total Design Length	11215,0
20	1	Tube 76,2 x 1,65 mm, [illegible]	43
19	1	Tube 76,2 x 1,65 mm, [illegible]	1034
18	1	Tube 76,2 x 1,65 mm, [illegible]	388
17	1	Tube 76,2 x 1,65 mm, [illegible]	982
16	1	Tube 76,2 x 1,65 mm, [illegible]	388
15	1	Tube 76,2 x 1,65 mm, [illegible]	982
14	1	Tube 76,2 x 1,65 mm, [illegible]	388
13	1	Tube 76,2 x 1,65 mm, [illegible]	1082
12	1	Tube 76,2 x 1,65 mm, [illegible]	384
11	1	Tube 76,2 x 1,65 mm, [illegible]	385
10	2	Tube 76,2 x 1,65 mm, [illegible]	185
9	1	Tube 76,2 x 1,65 mm, [illegible]	257
8	1	Tube 76,2 x 1,65 mm, [illegible]	499
7	1	Tube 76,2 x 1,65 mm, [illegible]	88
6	1	Tube 76,2 x 1,65 mm, [illegible]	300
5	2	[illegible]	56
4	2	Pipe bend 45	180
3	2	Pipe bend 45 [illegible]	150
2	10	Pipe bend [illegible]	[illegible]
1	10	[illegible]	[illegible]

ADD-ON HOLDING CELL
DIRECT HEATING THERMAL PROCESSING SYSTEM
HOLDING CELL CONSTRUCTION LAYOUT
71 GPM @ 4 SECONDS

Illustration provided by Tetra Pak

Hold Tube Size Calculator	Yellow	User Fill
	Grey	Calculated
	Orange	Based on water or standard tubing. Enter actual data if desired.
Tubing Data		
Tube Outside Diameter (inch)	3	Note: Standard sanitary tubing is specified by the outside diameter
Wall Thickness (inch)	0.065	
Fouling Thickness (inch)	0	Optional - Used for flow area calculation
Effective Inside Diameter (in)	2.870	Note: Tubing OD less wall thickness and fouling
Flow Area (in^2)	6.47	
Flow Input		
Max (Cut-Out) Flow (GPM)	78.1	Note: Nominal System flow or higher
Holding Temperature		
Minimum (Cut-Out) Temp (F)	284	
Operating Temp above Minimum (F)	6	
Operating Temp (F)	290	
Steam Data		
Steam Pressure at control valve inlet (PSIG)	80	
Steam Temp (F)	323.0	
Steam Latent Heat (BTU/lb)	892.7	
Direct Heating Correction		
Injector Inlet Temperature (F)	180	
Injector Temperature Rise dT (F)	110	
Product Specific Heat (BTU/lb-F)	1	Note: Use 1.0 for water if not known
Added Condensate (% calc)	11.87%	Note: Direct heating will add volume, increasing the flow rate
Added Condensate (% to use)	12.00%	Note: Use 0 if indirect heating (no injection or infusion)
Product Density Correction		
Temperature at timing device (F)	180	Note: Temperature at timing pump or flow meter
Specific Gravity at timing device	0.970	
Specific Gravity in holding tube	0.923	
Specific Gravity Correction (calc)	1.051	Note: Accounts for change in volume due to temperature
Specific Gravity Correction (to use)	1.06	Note: Use 1 for no density correction
Flow Regime Correction		
Corrected Max. Flow Rate (GPM)	92.7	Note: Actual flow in holding tube
Average (Volumetric) Velocity (ft/sec)	4.60	
Product Dynamic Viscosity (cP)	1.00	Note: Viscosity at holding tube temperature
Reynolds Number (Re)	94208.43	
Flow Correction for fastest particle (to use)	2	Note: Flow correction factor is 2 for laminar flow and 1.2 for turbulent
Fastest Particle Velocity (ft/sec)	9.20	
Lethality Residence Time Calculation		
Lethality Reference Temp (F)	250	
Lethality z-value (F)	18	
Target Lethality - F (minutes)	5	
Residence Time required (sec)	3.87	Note: Required holding time for fastest particle
OPTION 1 - CALCULATE HOLDING TUBE LENGTH		
Residence Time required (sec) (to use)	4.00	
Fastest Particle Velocity		
Minimum Hold Tube Length (ft)	36.8	
Minimum Hold Tube Length (in)	441.5	11213.36194
Average Velocity		
Minimum Hold Tube Length (ft)	18.4	
Minimum Hold Tube Length (in)	220.7	
OPTION 2 - CALCULATE RESIDENCE TIME		
Actual Hold Tube Length (in)	441.6	
Actual Hold Tube Length (ft)	36.8	
Average Residence Time (sec)	8.00	
Fastest Particle Residence Time (sec)	4.00	
Lethality - F (minutes)	5.16	Note: Based on fastest particle residence time

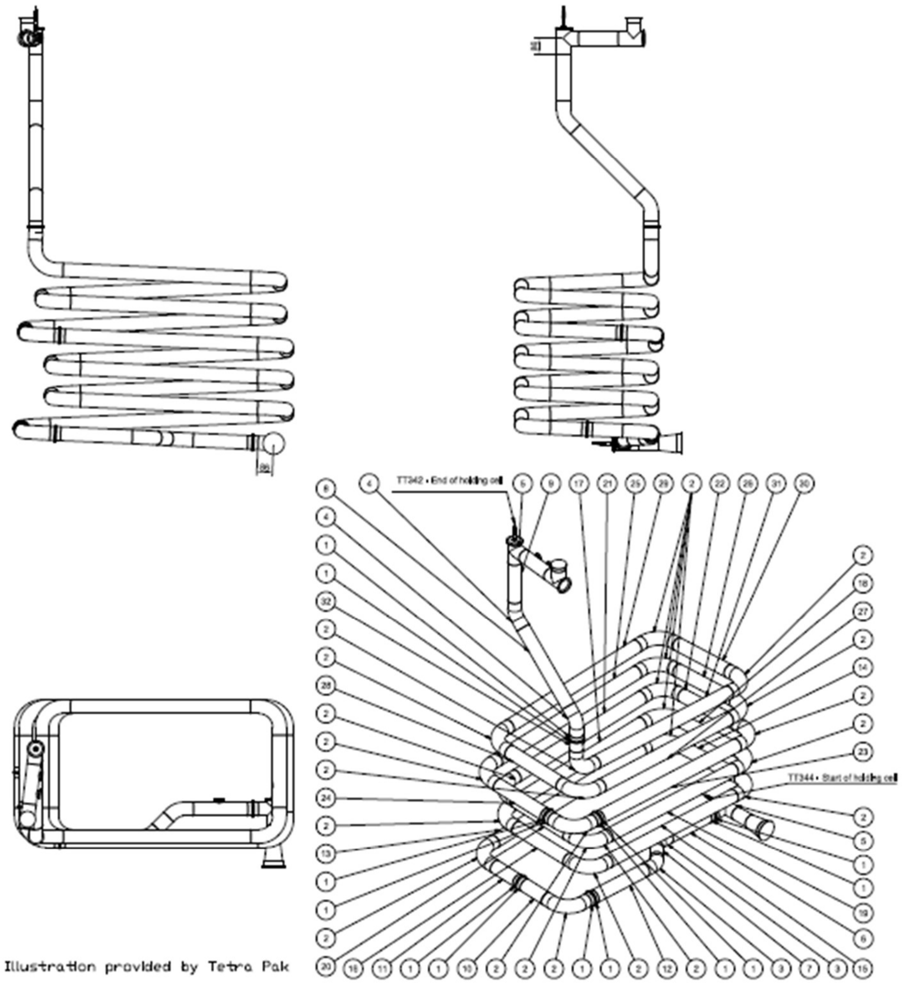


Illustration provided by Tetra Pak

Notes:
All tubing is designed at a 2,5° slope
unless otherwise dimensioned

All Dimensions are in millimeters
unless otherwise noted

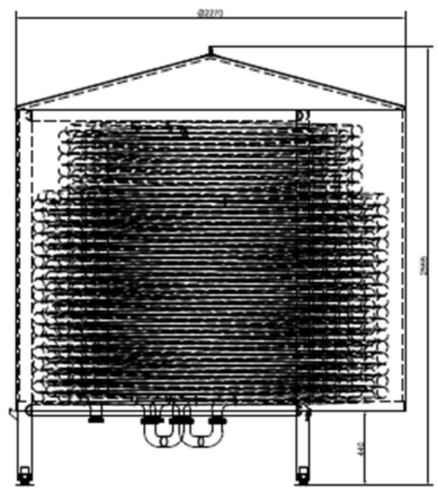
Nominal system flow: 142 GPM
Maximum cutout flow: 156.2 GPM
Minimum residence time: 4,0 seconds
Laminar flow profile correction
Minimum calculated length: 882.9" = 22427mm

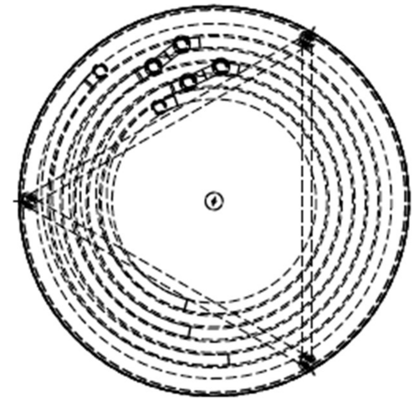
HOLDING CELL CALCULATION			
Pos.	ITEM QTY	Description	Length
		Total Design Length	22526
32	1	Tube 76,2 x 1,65 mm, SS818	43
31	1	Tube 76,2 x 1,65 mm, SS817	1034
30	1	Tube 76,2 x 1,65 mm, SS816	398
29	1	Tube 76,2 x 1,65 mm, SS815	892
28	1	Tube 76,2 x 1,65 mm, SS814	398
27	1	Tube 76,2 x 1,65 mm, SS813	892
26	1	Tube 76,2 x 1,65 mm, SS812	398
25	1	Tube 76,2 x 1,65 mm, SS811	1082
24	1	Tube 76,2 x 1,65 mm, SS810	304
23	1	Tube 76,2 x 1,65 mm, SS809	1082
22	1	Tube 76,2 x 1,65 mm, SS808	422
21	1	Tube 76,2 x 1,65 mm, SS807	878
20	1	Tube 76,2 x 1,65 mm, SS806	398
19	1	Tube 76,2 x 1,65 mm, SS805	878
18	1	Tube 76,2 x 1,65 mm, SS804	398
17	1	Tube 76,2 x 1,65 mm, SS803	878
16	1	Tube 76,2 x 1,65 mm, SS802	398
15	1	Tube 76,2 x 1,65 mm, SS801	878
14	1	Tube 76,2 x 1,65 mm, SS800	398
13	1	Tube 76,2 x 1,65 mm, SS499	1143
12	1	Tube 76,2 x 1,65 mm, SS498	395
11	1	Tube 76,2 x 1,65 mm, SS497	174
10	2	Tube 76,2 x 1,65 mm, SS496	168
9	1	Tube 76,2 x 1,65 mm, SS301	257
8	1	Tube 76,2 x 1,65 mm, SS300	499
7	1	Tube 76,2 x 1,65 mm, SS216	89
6	1	Tube 76,2 x 1,65 mm, SS202	300
5	2	Tubes BPE BTW/MEW-3 316L/PL Equal T	86
4	2	Pipe bend 45	100
3	2	Pipe bend 45	150
2	21	Pipe bend 3A 90 BDS W 316L 3"	268
1	10	Ferrule T14-CL	28

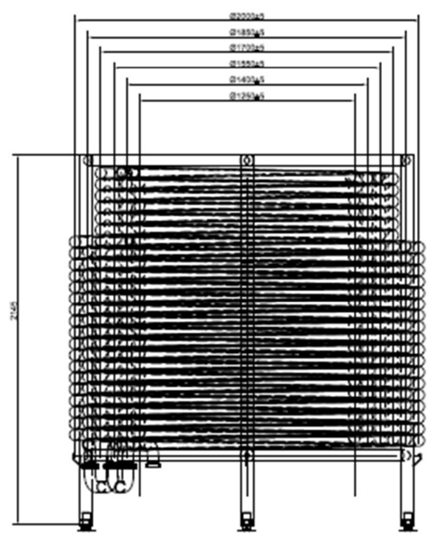
ADD-ON HOLDING CELL
DIRECT HEATING THERMAL PROCESSING SYSTEM
HOLDING CELL CONSTRUCTION LAYOUT
142 GPM @ 4 SECONDS

Hold Tube Size Calculator	Yellow	User Fill	
	Grey	Calculated	
	Orange	Based on water or standard tubing. Enter actual data if desired.	
Tubing Data			
Tube Outside Diameter (inch)	3	Note: Standard sanitary tubing is specified by the outside diameter	
Wall Thickness (inch)	0.065		
Fouling Thickness (inch)	0	Optional - Used for flow area calculation	
Effective Inside Diameter (in)	2.870	Note: Tubing OD less wall thickness and fouling	
Flow Area (in^2)	6.47		
Flow Input			
Max (Cut-Out) Flow (GPM)	156.2	Note: Nominal System flow or higher	
Holding Temperature			
Minimum (Cut-Out) Temp (F)	284		
Operating Temp above Minimum (F)	6		
Operating Temp (F)	290		
Steam Data			
Steam Pressure at control valve inlet (PSIG)	80		
Steam Temp (F)	323.0		
Steam Latent Heat (BTU/lb)	892.7		
Direct Heating Correction			
Injector Inlet Temperature (F)	180		
Injector Temperature Rise dT (F)	110		
Product Specific Heat (BTU/lb-F)	1	Note: Use 1.0 for water if not known	
Added Condensate (% calc)	11.87%	Note: Direct heating will add volume, increasing the flow rate	
Added Condensate (% to use)	12.00%	Note: Use 0 if indirect heating (no injection or infusion)	
Product Density Correction			
Temperature at timing device (F)	180	Note: Temperature at timing pump or flow meter	
Specific Gravity at timing device	0.970		
Specific Gravity in holding tube	0.923		
Specific Gravity Correction (calc)	1.051	Note: Accounts for change in volume due to temperature	
Specific Gravity Correction (to use)	1.06	Note: Use 1 for no density correction	
Flow Regime Correction			
Corrected Max. Flow Rate (GPM)	185.4	Note: Actual flow in holding tube	
Average (Volumetric) Velocity (ft/sec)	9.20		
Product Dynamic Viscosity (cP)	1.00	Note: Viscosity at holding tube temperature	
Reynolds Number (Re)	188416.85		
Flow Correction for fastest particle (to use)	2	Note: Flow correction factor is 2 for laminar flow and 1.2 for turbulent	
Fastest Particle Velocity (ft/sec)	18.39		
Lethality Residence Time Calculation			
Lethality Reference Temp (F)	250		
Lethality z-value (F)	18		
Target Lethality - F (minutes)	5		
Residence Time required (sec)	3.87	Note: Required holding time for fastest particle.	
OPTION 1 - CALCULATE HOLDING TUBE LENGTH			
Residence Time required (sec) (to use)	4.00		
Fastest Particle Velocity			
Minimum Hold Tube Length (ft)	73.6		
Minimum Hold Tube Length (in)	882.9		22426.72389
Average Velocity			
Minimum Hold Tube Length (ft)	36.8		
Minimum Hold Tube Length (in)	441.5		
OPTION 2 - CALCULATE RESIDENCE TIME			
Actual Hold Tube Length (in)	887.0		
Actual Hold Tube Length (ft)	73.9		
Average Residence Time (sec)	8.04		
Fastest Particle Residence Time (sec)	4.02		
Lethality - F (minutes)	5.19	Note: Based on fastest particle residence time	

Figure 11.2.4 Spiral Style – non-legal, extended







	OD	ID	Area	Coil D	L per coil	Slope	# Coils	Total L	Volume	Flow	Hold Time
	mm	mm	mm2	mm	mm	%	# w/els	m	L	L/hr	min
A	62.5	58.5	2688	1250	3927	1.59%	24.1	94.64	254		
B	62.5	58.5	2688	1400	4398	1.42%	24.3	106.88	287		
C	62.5	58.5	2688	1550	4869	1.28%	24.1	117.35	315		
D	62.5	58.5	2688	1700	5341	1.17%	23.9	127.64	343		
									1200	18000	4.00
E	62.5	58.5	2688	1850	5812	1.08%	18.5	107.52	289		
F	62.5	58.5	2688	2000	6283	0.99%	18.4	115.61	311		
								669.65	**1800**	18000	6.00

NOTE: Extended holding cell due to downward slop of alternating coils.

Illustration provided by Tetra Pak

SPIRAL STYLE HOLDING CELL
EXTENDED HOLDING TUBE
HOLDING CELL CONFIGURATION LAYOUT