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Handbook On Design & Operation Of Poultry Slaughterhouse – Chapter 11 – Chilling & Freezing Poultry

Preface

In terms of product quality, there are two steps in processing that matter most – scalding and primary chilling. This is not to run down the importance of the remaining process-steps, but to draw attention to the need for optimal equipment choice and to sensitize the process supervisor to the importance of these steps. While we cover scalding in Chapter 9, our handling of chilling in this chapter explains the science behind this step and explains the impact of market factors on the choice of proper chilling equipment.

In this chapter we have sometimes used the terms **cooling** and **chilling** interchangeably, although chilling is just another name for the physical process of cooling. As long as the act of cooling refers to meat from its freshly slaughtered temperature of around 41°C¹ to just prior to freezing (actually down to +4°C), we remain justified in referring to our efforts as **cooling** or abstraction of sensible heat, and refer to it sometimes as **chilling**, more in deference to convention, than to impute any particular reason for doing so. When we continue the cooling process beyond the freezing point, we are still performing a cooling action, but again by convention, we now call it **freezing**. In like manner, some of the equipment we employ for **primary cooling** is called **chilling equipment** by convention.

Aptec's friend Dr Shashidhar Ramachandra is a voluntary contributor to this Chapter on two sub-topics - (1) the theoretical explanation of cooling of poultry meat and (2) the importance of bubbling compressed air into the immersion chilling bath with a clear refutation of the erroneous belief that heat introduced by the process of compressing air for this purpose has a deleterious effect on chilling carcasses. We are thankful for his contribution. Meanwhile, although the main narrative on these sub-topics only states simplified abstracts, Aptec will be happy to e-mail Dr Shashidhar's complete papers to any reader upon request.

Dr Shashidhar is currently working with the University of Bristol in the UK on a project funded by United Kingdom Research and Innovation (UKRI) focusing on application of aircraft data analytics for landing gear fatigue design and is engaged in solid mechanics with a specialisation in material fatigue analysis using Artificial Neural Networks (ANNs). He traces his roots to the poultry business and hopes someday to set up his own poultry integration and processing in his native state of Karnataka.

Aptec's document titled *Chilling, Chiller Design and How to Choose a Good Machine* dated 25 May, 2018 has been incorporated into this chapter, which now forms part of the Handbook project of Aptec. With the uploading of this Chapter, the document of 2018 has been withdrawn. The section on diagnostics and troubleshooting has been removed from the original. Diagnostic and troubleshooting now forms a separate Chapter of this Handbook.



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1 Why Do We Chill Poultry?

When they emerge from the evisceration section, poultry carcasses are at a high temperature – typically around 41°C. This temperature is ideal for the growth and multiplication of some infection and spoilage bacterial and therefore the carcass must be rapidly brought down to as near 4°C as possible, because at this lower temperature microbial activity and multiplication is virtually arrested. Therefore chilling is the single most important factor in ensuring product quality, food safety and shelf-life.

Following evisceration and washing, all dressed poultry carcasses shall be chilled to 4°C or lower within the time prescribed in table 1.

Under 1.8 kg (4 pounds)	4 hours
1.8 to 3.6 kg (4 to 8 pounds)	6 hours
Over 3.6 kg (8 pounds)	8 hours

Table 1 Prescribed delay limits for carcass wash for different poultry carcass sizes according to FSIS.² These include the time required to bring down the temperature – larger carcasses taking longer to cool.

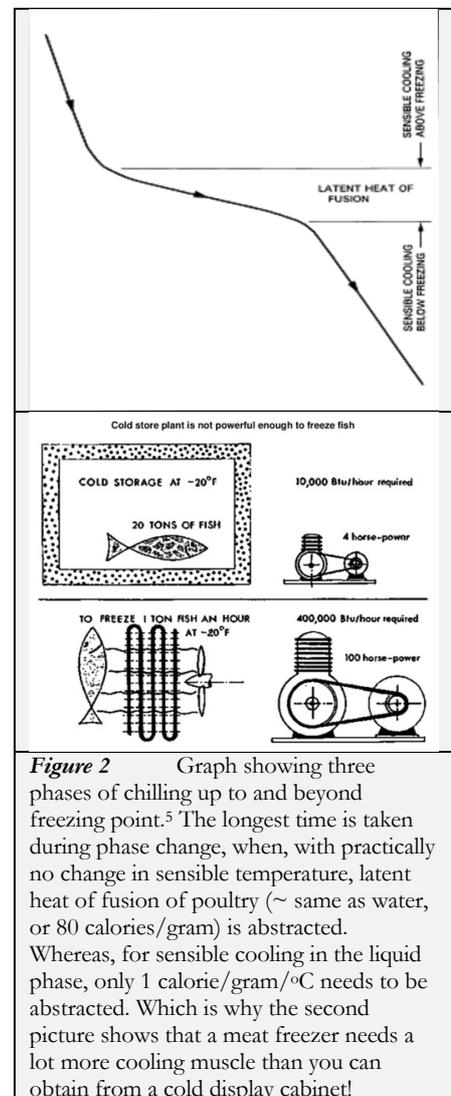
2 Chilling, Freezing & Thawing Of Meat³

Chilling of poultry is essentially a three step process during which we remove heat energy from it, usually with simultaneous drop in measurable temperature and sometimes with no accompanying measurable drop. As we continue the chilling process, we obtain chilled poultry and if we persist, we get frozen poultry. We chill to virtually stop bacterial activity if the product is to be sold fresh-chilled, whole carcass, portions or boneless pieces - to be consumed within a very short time – typically less than a week. On the other hand, if the product has to be stored for longer periods, we must freeze it by taking the temperature below -18°C⁴.

The first chilling objective is called **primary chilling** and is most efficiently done with the help of very cold water supplemented with ice flakes. Freezing can be achieved with the help of very cold air, contact freezing by plate freezer or cryogenic methods. Since water freezes at 0°C, it is impractical to perform cooling of carcasses or portions below 4°C⁶ using cold water or ice slush in water.

What happens when we freeze poultry, or for that matter, when we freeze any soft animal tissue? The mechanism has been reported in detail by the FAO for **cryopreservation** of animal genetic material such as bovine sperm.⁷ Because it is concerned with preservation of genetic material in a **viable** form, its recommendations cannot be directly taken by us because our needs differ. We do not need to preserve meat in a viable form, but only preserve the nutritional and organoleptic properties of meat and if possible, also damage or inactivate harmful microbes in the process. But the conclusions drawn from this study have direct application in our understanding of the mechanism of freezing, so we have chosen this article for scrutiny.

Table 3 lists the main physical changes that occur when we cool soft animal tissue and cause it to freeze. We have the choice of cooling it either slowly or rapidly. How the speed of cooling governs the physical changes at the cellular and tissue level depends mainly on the behaviour of liquid water; specifically the behaviour of **intracellular** and **intercellular** liquid water across cell membranes. Chilling causes formation and growth of ice, which is a relatively rapid process depending on rate of energy abstraction, but transport of water across cell membranes occurs relatively slowly. Therefore, as chilling and growth of extracellular ice continues, liquid water in unfrozen portions within the tissue mass remains very close to equilibrium with the ice, but water within cells lags behind in freezing. This means that formation of ice crystals may begin inside cells and although these ice crystals may be small or large (we shall discuss the crystal size aspect later), nevertheless, removal of pure water⁸ by the formation of ice crystals upsets the liquid water equilibrium, causing **concentration** of the remaining solution within the cell or effectively **dehydrating** the cell contents. In effect, the remaining



unfrozen water contains a progressively increasing concentration of naturally present dissolved salts, proteins and other compounds.

Additionally, this increasing concentration may lower the freezing point of the remaining unfrozen water so that it now freezes at below 0°C.¹⁰ The result is that, unlike pure water, complete change to ice is not accomplished at a fixed temperature of 0°C, but proceeds over a range of temperatures - typically below¹¹ the freezing point of pure water.

Effect of Low Temperature & Chilling Rate On Meat	
Findings reported in the source document	Interpretation
Temperature may affect membrane lipids & proteins. The former, normally in a liquid crystalline state, may solidify, causing damage or loss of function.	Damage, injury or loss of function of tissue matters for cryo-preserving genetic material but not for meat.
Cells of warm-blooded animals may be damaged by low temperature <i>per se</i> (chilling injury) or by very rapid chilling (cold shock).	
When cells are chilled very slowly, intracellular water lags behind only a little, and the risk of intracellular ice formation is minimal but cell dehydration is maximal, which is not desired when cryopreserving living tissue.	
At higher chilling rates, intracellular dehydration, intracellular solute concentration & shrinkage of the cells are less and cells face unfavourable conditions for shorter time periods.	
Table 3 Detailed analysis of chilling rate on animal tissue obtained by this FAO study is aimed at the cryopreservation of animal genetic material. It has been re-interpreted here to see if and how these findings affect meat chilling and thus use these findings to develop the best freezing rate for preservation of animal tissue for eating ⁹ .	

What kind of chilling rates are necessary for the formation of ice crystals inside cells? This aspect has been well reported by Juneja et al¹³ and covers the subject of intracellular ice formation in bacterial cells. For such ice to form rapidly or almost instantaneously, you require a very high cooling rate - in excess of 10°C/min. Such a rapid rate of cooling may be obtained at surfaces treated with cryogenic liquids or even by conventional IQF (individual quick freezing) process meant for shrimps, peas and other small items, but is unlikely in any industrial scale food-production process meant for chilling chicken carcasses using conventional industrial refrigeration equipment. This indicates that formation of ice crystals with consequent mechanical damage to cell membranes cannot explain fluid loss during thawing.

Freezing systems for poultry carcasses are often labelled **IQF** tunnels. This is an incorrect name to be given to such systems because neither does freezing occur **quickly** in them, nor do carcasses get **individually frozen** in these tunnels. Freezing of poultry carcasses is a slow process and occurs typically over **four hours** in a blast freezing (BF) chamber.

Exactly how rapidly does freezing of meat occur? To answer this question we must first examine the response to freezing cold that cells exhibit and how components within cells respond to such conditions. Freezing does not occur instantly but happens over a period of time and across a zone of declining temperature as illustrated in figure 4.

We have stated in Chapter 6 that the major ingredient within meat is water. Now the cellular and intracellular environments in meat contain a large number of dissolved substances within that water, with many of them being soluble proteins. These dissolved substances control the **pH**, the **buffering status** and the **osmotic pressure** within their environment, and by virtue of these controls, ultimately the physiology of the cell. As freezing progresses within that environment, more and more free water turns into ice and the result is **dehydration** within the meat and loss of control.

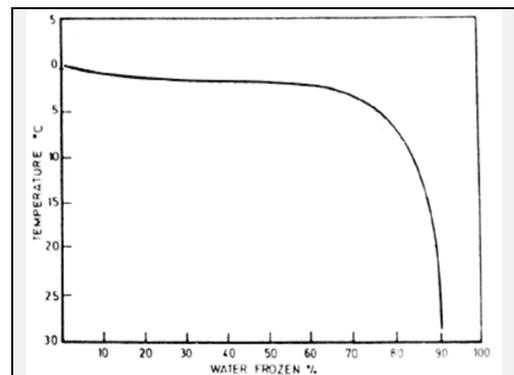


Figure 4 Freezing of fish muscle showing the percentage of water frozen at different temperatures¹². In this case freezing commences at about -1°C and about half the water in the tissue gets frozen at -2°C. But even at -40°C some 10% of the water, which is associated with structural proteins, remains unfrozen.

With dehydration pH, buffering environment and osmotic pressure within the cell also change because these are normally held in a dynamic balance, with one factor influencing others. In other words a positive feedback is set in motion. Consequently, all three conditions become sub-optimal - not just to the continuation of physiological functions (about which we are no longer concerned), but also the **organoleptic properties** of meat. This mainly happens because some of the dissolved protein molecules, which in their native form determine the organoleptic properties of meat, become **denatured**. We are now seriously concerned because the organoleptic properties of meat are the very ones that we are preoccupied with because they determine its perceived quality!



Egg white, contents of whey and blood plasma are some common examples of water-soluble proteins. To understand how proteins get denatured, recall what happens when you heat egg white. Its colour, appearance and taste change. Granted, in the case of egg white, this process of denaturation improves its organoleptic properties, but this is seldom the case accompanying denaturation. Denaturation is generally permanent and consist of alteration of the three-dimensional structure of protein molecules which are large and often have right and left handed properties¹⁴. And, these very properties determine the biological functions of proteins. Denaturation or removal from solution makes proteins fail in their designated functions or properties – some of which may be organoleptic in nature. For more on the structure of protein molecules, their mechanism of biochemical reactions and the effects of protein denaturation, refer to Chapter 13.

Thus, as the intercellular water is frozen out as pure ice, the higher concentration of compounds in the unfrozen liquid phase results in acceleration of denaturation throughout. Some of these phenomena act in opposition to each other as temperature is reduced and it has been demonstrated that the **temperature of maximum activity** for poultry meat is in the region of -1 to -2°C. It is therefore of utmost importance to transit this temperature band as rapidly as possible when you blast freeze meat. When transition is rapid, these changes are limited. Yet, as you will see in table 8, transition across this phase accounts for most of the energy (86%) needed for freezing meat. So, to retain meat's natural properties as faithfully as possible, meat must transit the temperature of maximum activity as rapidly as possible and correspondingly the **refrigeration system must have sufficient muscle power to extract such a large amount of heat energy is as short a time period** as possible.

Variation in the proportion of liquid water (which reduces as more and more of it gets converted into ice) in the muscle tissue against temperature is shown in Figure 4. This figure shows that by the time the temperature of meat (fish carcass in this example) is reduced to -5°C, about 70% of the water is frozen. It also shows that even at temperatures as low as -30°C, a proportion of water in the muscle still remains in the unfrozen state. All meat types, whether poultry, swine, goat or fish, share this property. This residue of liquid water in frozen meat has serious significance for the survival of some **psychrophiles** or cold-tolerant bacteria, a fact about which you may learn in Chapter 7.

Although the FAO document from which table 3 has been derived, has been in the public domain for decades, it has not been studied for the purpose of re-interpreting the findings in the interest of meat preservation in the manner that we have done here. Therefore public domain literature on the freezing of meat often remains incorrect, confusing and contradictory. This is particularly the case when reference is made to the difference between slow and quick freezing. Much of the literature, still in circulation, incorrectly proposes that the problem with slow freezing is due to the formation of large ice crystals which damage cell membranes with their sharp edges and this causes inter-cellular fluids to leak out when meat is thawed.

We think that proponents of this thaw-loss hypothesis were tunnel-visioned botanists, thinking of water within xylem cells whose naturally **rigid** cellulosic cell walls (further strengthened by the inclusion of lignin or silica), makes them prone to mechanical damage or puncture. By contrast, animal muscle cells possess **flexible** cell membranes, composed not of rigid cellulose, but of flexible lipid, protein and lipo-protein molecules. We discuss some of these myths in this Chapter, but before we do so, we need to understand the physics of cooling.

2.1 The Physics Of Cooling

We instinctively understand hot and cold and how hot objects cool and cold objects heat up. But to mathematically explain the phenomenon we turn to Newton. His law of cooling states that the rate at which an object's temperature changes is directly proportional to the difference between its temperature and the surrounding ambience, or that the hotter an object, the faster it cools. But this Law holds true only (1) for small temperature differences, (2) as long as the temperature of the surroundings remained constant and finally (3) if transfer of heat occurs only by radiation.

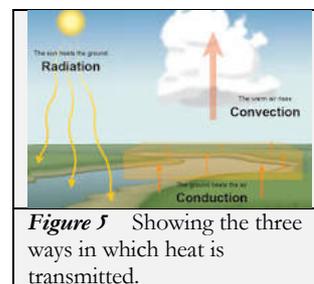


Figure 5 Showing the three ways in which heat is transmitted.

Cooling of poultry carcasses embraces all three exceptions to Newton's Law of Cooling. First of all the poultry carcass is at an initial 41°C while the chilling medium in immersion chilling is at 2°C¹⁵ or for air chilling, at near 0°C. This temperature difference, although not very small, is definitely not insignificant. Next, the temperature difference in the case of immersion chilling does not remain constant unless we keep adding sufficient quantity of flake ice to the bath. Finally exchange of heat occurs in immersion chilling by not only radiation, but also by



conduction. In fact conduction is by far the most important heat exchange mechanism involved here. And in the case of air chilling, conduction is still the most important process of heat exchange.

Figure 5 shows the three means by which heat is transmitted. For the example the artist has chosen radiant heat from the sun, arriving through the vacuum of space and heating the atmosphere and everything within it in turn by conduction. We can move into the shade to avoid radiation but conduction still persists in warming us. Also, because hot air expands and becomes lighter than cold air, it rises and takes heated air up. This is convection. When we chill poultry, exchange of heat occurs mostly by conduction. Convection and radiation play a less significant role in the process.

As scientists studied the mathematical expressions and experimental findings related to heat and its manifestations, they gradually learnt about the nature of energy and matter. Modern scientific knowledge and engineering methods owe a lot to their curiosity and discoveries. Among the findings, the most important ones relate to the phases or forms in which matter exists.

Matter is made up of fundamental building blocks called atoms which can chemically bond together to form aggregates called molecules. Matter can exist in nature in three phases - solids, liquids and gases - with gases holding the most energy and solids the least. Differences in levels of energy among phases of matter is defined as **latent heat** which is a value constant for every phase transition. So the latent heat of fusion of water is 80 calories per gram while the latent heat of vaporization of water is 540 calories per gram. Put in another way, it takes 6.75 times more energy to vaporize water than it takes to turn it into ice. And the converse is also true – a gram of ice needs 80 calories to turn to water and another 540 calories to turn to steam. Latent heat of sublimation refers to the energy it takes for substances to change directly from solid phase to gaseous phase, skipping altogether the intermediate liquid phase. Camphor is a common solid that sublimates.

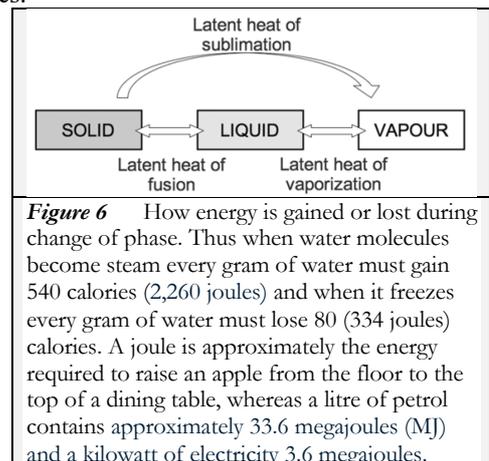
Initial investigations into the nature of heat led initially to its characterization as a mythical fluid labelled phlogiston (which could flow from hot to cold objects) and later to formulation of the **Laws Of Thermodynamics**. With the formulation of these Laws, the phlogiston hypothesis was discarded. The first of these Laws states that energy can neither be created nor destroyed – it merely converts from one form to another. Simply put, it means that you lose 80 calories when you freeze a gram of water and you regain the same amount of energy when you thaw it.

The Second Law states that (given a closed system), as energy transitions from one form to another, the level of atomic or molecular randomness or disorder increases. It further implies that for any spontaneous process, the total **entropy** (roughly meaning level of disorderliness of an isolated system – whether that system is the confines of a room with certain properties, or the entire universe, for that matter!) always increases, or at best remains constant.

In other words, natural processes tend to move toward a state of greater disorder or randomness. Digging deeper into the statement we find that heat flows naturally from a hotter object to a colder one and that it's impossible to convert heat from any one source **completely** into work without any other changes occurring. Finally this Law demonstrates **the arrow of time**, that it is one-directional and explains why ice melts in the bath instead of every once in a while forming spontaneously from the chill water.

The Third Law was arrived at through theoretical research and has implications for the nature of matter and energy. By this law, the state of randomness means the state of movement or vibration of atoms, whether the substance they form be in the gaseous, liquid or solid state. Within gases, atoms have the highest amount of energy, which condition the atoms express by rapid and random movement. In the liquid form, they possess less energy and exhibit less motion. And within solids, atoms remain within crystalline structures or lattices – rather like soldiers assembled for parade.

As their energy content diminishes, eventually atoms come to a state of perfect rest within the crystalline arrangement, and that eventual state of zero motion exhibits the absolute zero level of measurable temperature. This level has been named **Absolute Zero** and occurs at -273.15°C . Scientists¹⁶ are even today in a rush to come



closer and closer to absolute zero in the laboratory to understand the behaviour of matter and energy. Work continues even to this day and fascinating new information is generated from time to time from such pursuits. So now that you understand and appreciate the process, you can make every carcass in your chiller dance to your tune!

2.2 Myths & Truths About Freezing Of Meat

Myth One (Mechanical Explanation) At first it was proposed that rapid freezing was unsatisfactory since it could, by this simple process, tear muscle tissues and cause water to flow out during the freezing step itself and/or on thawing.

Myth Two (Mechanical Explanation) It was also thought that since water expands on freezing, it might be reasonable to expect that as cellular contents froze, their watery components would expand as they turned into ice and this increased pressure could damage or rupture cell membranes and some of the water would flow out, to be readily available as thaw-loss since they would not any longer be confined within cells.

Myth Three (Mechanical Explanation) For some time after that, it was widely believed that besides the above problems, slow freezing resulted in the formation of larger ice crystals inside cells, whose sharp ends could pierce and so damage cell membranes, causing loss of fluid upon thawing. Smaller ice crystals formed by rapid freezing were thought to do little damage to cell membranes and, consequently, less fluid was lost on thawing.

Piercing of cell membrane is not the correct explanation of the loss of fluids either during or after freezing and upon thawing of meat, as we have already explained. Firstly there is no evidence of icicles with sharp edges developing inside muscle cells. Secondly, animal cell membranes are sufficiently elastic and can accommodate sharp-edged icicles without getting punctured. Finally, most of the water in muscles is bound to the protein in the form of a gel and is not free-flowing water, so that very little of it would be lost on thawing even if damage of the above nature did occur unless the gel structure itself were to get destroyed and liquid water thus released. And if we admit that the gel structure does get destroyed, we are taken back to the explanation about osmotic pressure, pH and buffering properties which promote gel formation.

Myth Four (Fresh chilled poultry is safer than frozen poultry). FAO/WHO Global Forum of Food Safety¹⁷ reported on a human *campylobacteriosis* epidemic. Over the period June 1998 - March 2000 the incidence of human *campylobacteriosis* reached epidemic proportions in Iceland. The epidemic was almost exclusively due to an increase in domestically acquired infections, mostly traced to the consumption of fresh chicken. Based on government regulation prior to 1996 it was only permitted to sell frozen poultry in food stores, but with the change of regulations fresh poultry was allowed and sales increased significantly. So did human *campylobacteriosis* – showing a direct correlation. Chapter 7 carries more details on safety differences between frozen and fresh chilled meat.

2.3 Sensible & Latent Heat

Suppose you briefly touched a portion each of unfrozen and frozen meat, both at a temperature of approximately -1°C, (this, as mentioned above, being the lowest temperature at which meat can exist in both frozen and unfrozen states). You would not be able to tell which felt colder to your touch. This is because although that piece of frozen meat holds less energy (in the form of lost latent heat energy of -80 calories per gram), its sensible temperature was the same as that of a piece of unfrozen meat. **Sensible** temperature is something which we can **sense** by touch, and can likewise measure with a thermometer. **Latent heat energy**, on the other hand, cannot be sensed either by touch or thermometer. When you cool poultry carcass from its initial 41°C down to a frozen state, you remove both sensible heat (energy) and latent heat (energy) from the carcass. Moving a poultry carcass, which has already been cooled down to nearly its freezing point and then across the freezing stage, involves removal of both sensible and latent heat. A detailed analysis (table 8) will explain this.

2.4 Compressor Power & Freezing Speed

Look again at figure 2. In it the artist has tried to convey, with the help of two differently sized refrigeration compressors, that different amounts of energy are needed to chill and freeze fish. The graph in that figure shows that the product temperature (**sensible** temperature) falls steadily as a compressor performs its cooling function, but during the period in which **phase change** - meaning **transition of cold fish into frozen fish**- occurs, the



sensible temperature of the product remains constant for a length of time (note how the line remains horizontal throughout this stage) - till the product almost completely freezes over and the next cooling phase, i.e., further cooling of frozen fish, starts. At this point the line curves downwards.

In other words, the graph shows that the chilling-freezing process has occurred in three **phases**. The first was accompanied by a steady drop in sensible temperature. The second showed no change in sensible temperature while the third once again showed a steady change in sensible temperature. This three-stage phenomenon has been explained in table 8 where we have calculated the difference in effort required to first chill, then freeze poultry and finally to take the temperature of frozen poultry further down the negative scale. In this table we have calculated energy figures for a kilogram of poultry meat initially at +4°C, which was sent to the blast freezer and progressively brought down to -20°C.

In practical terms, when you perform freezing of poultry carcasses in your blast freezing chamber, your action essentially performs the third cooling phase. It continues to remove sensible heat down to around -10°C at the core of the carcass even as the surface reaches around -30 to -40°C. Temperature across the entire carcass later equalizes within a 24 hour period in the frozen store, to the thermostat set point in your frozen store, which may be -18 or -20°C. During the storage period the evaporator in your frozen store does not remove energy from meat – it just compensates for the heat ingress into the store through walls, roof and floor, from warm air rushing in when doors are opened and from warm human bodies working in the store.

The longest part of the freezing process is the removal of the latent heat of fusion as water turns to ice or as fresh poultry freezes. Poultry meat is particularly sensitive as it transitions this temperature of maximum activity because in this zone quality, nutritional value, and appearance of meat are most vulnerable. The longer it takes to perform this step, the worse do these indicators get. Thus, the freezing method and system you select can have substantial impact on product quality and economy. When the refrigeration system is **under-powered** (this being the most common culprit!), this stage takes long and meat quality suffers, But if the system is adequately powered, this step is completed rapidly and meat quality suffers very little. This is why we have given the type AA pen-lite cell analogy in table 8.

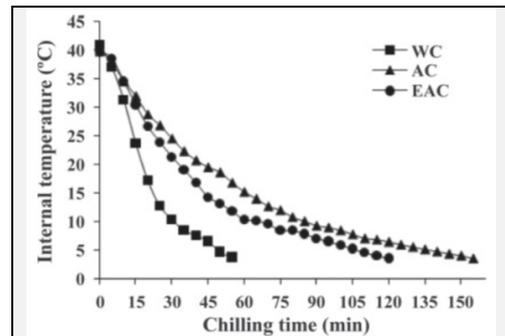


Figure 7 Time taken for primary chilling using different methods - water (WC), air (AC), & air-chill with spraying (EAC)¹⁸ In this figure the internal carcass temperature was 39.9°C at the beginning and decreased to 4°C, with average chilling times of 55, 155, and 120 min for WC, AC, and EAC, respectively.

Energy (in the form of heat) abstracted or removed in each step	Formula		Value
Energy removal by chilling from +4°C to 0°C	1000g x 1 calorie/°C/g x 4°C - 0°C	=1000x1x4	4,000 calories
Energy removal in the process of freezing	1000g x 80 calories/g		80,000 calories
Energy removal by chilling from 0°C to -20°C	1000g x 0.5 x (0 ~ -20°C) (for frozen poultry the specific heat is approx. the same as ice, i.e. 0.5)	=1000 x 0.5 x20	10,000 calories
Total energy removal	4,000+80,000+10,000		94,000 calories
Percentage of energy removal in each step	Step 1 = 4.2%; Step2 = 85.1%; Step3 = 10.7%		

Table 8 Simplified calculations showing how much heat energy needs to be removed from 1 kg of poultry meat in freezing from an initial +4°C to -20°C by your blast freezing system. Here, for simplicity we have taken 0°C as the freezing temperature, although the freezing process of almost all of the poultry meat more or less ends at around -1°C). Clearly, the lion's share of energy removal occurs during step 2, which is the freezing step.

These calculations also show that while a display cabinet has the capacity of **maintaining** products at -20°C, **cooling** raw unfrozen meat from +4°C to -20°C would be beyond its power. Much in the same way that eight pen-lite (type AA) cells, wired in series, may deliver 12 volts, but cannot start your car engine! The series arrangement adds voltage, but does not increase the deliverable amperage of the cell. In other words, we are in need of **power** to turn an automobile starter motor, not just **voltage**.

Figure 7 shows the relative speed of primary chilling using three methods – immersion chilling, air chilling and evaporative air chilling. This last method requires periodic spraying of carcasses in an air tunnel with water. This



method is not popular now but may become the preferred method in future. We discuss it in Section 9. At present water chilling (WC) and fogged air chilling (FAC) are more popular. In FAC carcasses are fogged with water as they enter the tunnel and a thin film of ice quickly forms over them. This film prevents carcasses from excessive desiccation in the tunnel. However, for our comparison purpose EAC may be considered equal to initial fogging. In each case consider the time it takes the carcass to reach a core temperature of 4°C, approximately 40 to 60 minutes, depending on carcass size, for WC and 140 to 150 minutes for FAC.

2.5 Why Sodium Ion Balance Is Important For Tenderness

You may have wondered from time to time, that given the broad uniformity of composition of the typical slaughtered animal, why is meat sometimes tough and sometimes dry or lacking in succulence? Do the structure of meat, the condition of slaughter or the processing steps following slaughter have any role to play in imparting these properties?

To answer this question, we must examine the nature of meat, more specifically bundles of muscle and how ionic balance within them affects tenderness and succulence. The topic has been discussed at length in Chapter 6, Section 1.2 on the structure and biochemistry of meat. We summarize the salient facts here.

The process of converting a living meat animal to meat begins with the removal of blood. This action initiates a series of chemical and physical changes in the animal's body that lead to muscle rigidity known as *rigour mortis* which is a Latin phrase meaning 'stiffness of death'. If rigour mortis occurs before the muscle mass has begun to cool (which occurs when you slaughter poultry), contractile proteins within the muscle and skin denature and lose many of their properties, including their ability to hold water.

Muscles are made up of a number of protein building blocks called **amino acid** molecules. When the pH of the muscle is 7, or neutral, these amino acids are negatively charged and so they repel each other. This creates physical space between strands of amino acid sequences and this space is occupied by water molecules. At around pH 5.5 the negative charge becomes nil, so there is no repulsion between muscle bundles, therefore no space, so meat holds the minimum amount of water. This ability of muscle to hold water is called its **water holding capacity** or **WHC**.

So how does the pH fall and reduce the WHC? After slaughter, as rigour mortis sets in, **glycogen** in the muscle is converted into **lactic acid**, causing a fall in pH from an initial value close to neutral (6.8 - 7.3) to about 5.4 - 5.8. Given the right temperature, in poultry the end of rigour mortis occurs in approximately 4-5 hours following death. During this period adding salt restores the negative charge and WHC is restored and even after the end of rigour mortis around 4 - 8% of common salt or sodium chloride seems to be most effective for improving this negative charge. Addition of sodium ion in one form or another is very common in production of RTE items for improving the WHC of meat, as explained in Chapter 6.

But when we produce raw poultry meat, we cannot enhance sodium ion concentration to restore the WHC, although we certainly can ensure that enough water is present to allow the meat to regain its WHC at the end of rigour mortis. Water pickup in immersion chilling helps to do this. When the WHC of meat is fully restored, the meat no longer tastes dry or appear lacking in succulence. As the process of rigour mortis concludes, water picked up during chilling migrates into the mass and succulence is restored. We can conclude this explanation about succulence of meat with the statement that the water-holding capacity is of particular importance in meat processing. One of the important aims of processing, preserving and otherwise improving meat is to restore this water, and, to the extent possible, to augment the WHC of meat. The ethical angle of adding water to meat is another matter and is covered in another section of this Chapter.

2.6 Thawing Meat

There are three safe ways to thaw chicken meat: in the refrigerator, in running tap water and in the microwave. The water and microwave methods require that the carcass be cooked immediately after thawing, but while meat is in the process of thawing in the refrigerator (at settings of 4°C or so), it remain safe. After thawing, use ground meats, poultry, and fish within one or two additional days, and use beef, pork, lamb or veal (roasts, steaks, or chops) within three to five days – provided that after thawing they are stored safely back in the refrigerator¹⁹. When thawing meat and poultry in the microwave, plan to fully cook it immediately because some areas may have warmed or even begun to cook. Storing partially cooked meat is not recommended because any bacteria present on it may have escaped destruction and may instead have reached optimal temperatures for growth.



When marinating meat ensure that the process does not exceed 24 hours and that it stays in the refrigerator during this period. Boil the used marinade if you want to brush it on the meat or poultry while it's grilling and do not save marinade for future use. It is safe to keep the food in the marinade longer than 24 hours, but after two days the marinade would have caused excessive break-down of connective tissues, causing meat to become mushy. Marination has a two-fold objective – firstly to increase the sodium ion balance to allow water to enter and secondly by breaking down connective tissues within meat. The first adds succulence while the second breaks down hard-to-chew parts which no longer block the penetration of flavours and aroma from spices into them.

How can you bulk-thaw frozen chicken in the process plant? You can use some proprietary thawing equipment if you like, but the easiest way is to pass the frozen carcasses in an immersion chiller such as a screw chiller. Recall that the screw chiller design is optimised for **efficient heat exchange** and both cooling and warming are simply attempts at exchanging heat. When using the screw chiller in this role, make sure that the carcasses are dropped into the bath one by one – never drop large blocks of carcasses that have become stuck together. Doing so may cause the blocks to damage the machine by snagging between the screw and shell, ruining the screw or bending the shaft. If the flights on the screw get bent, do not attempt to straighten them in-situ. This may bend the shaft.

For thawing in this way, run water at ambient temperature through the machine and ensure that after thawing carcasses are kept at between -1 and +4°C and sold for immediate consumption because their shelf life is never more than 24 hours after this treatment. They do not any longer possess the usual shelf-life of genuine fresh-chilled poultry now.

Thawing of slow-frozen meat does result in a lot more fluid-loss than rapidly frozen meat does. This is because ice formed during freezing now melts and leaves the meat. Ice-melt cannot go back to dissolve the proteins which were once in it, because the process may have denatured these proteins and now they may have become insoluble. This water contain a lot of soluble nutrients which are an excellent nutrient-rich medium for microbes. This is why, **on thawing, meat spoils rapidly and has a shorter shelf-life**. Washing this melt off helps make the meat safer and last longer. You may also find that adding chlorine to the wash helps.

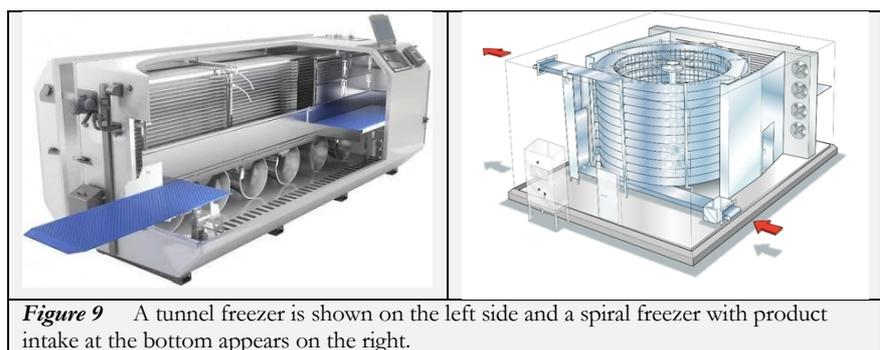
Summing up, we can conclude that with the development of blast freezing in 1949, the advantages of rapid freezing began to be appreciated and people theorized (often, as seen above, drawing incorrect conclusions) on the technological benefits of blast freezing over slow freezing. Advances in study of cell membranes, pursuit of synthetic membrane technology for industrial applications, and even the explanation in this document given in table 3 show that while there may be some layman logic in these theories, they do not explain the differences between slow and rapid freezing. We need to turn to consequences of **loss of chemical equilibrium within cells** covered above, to explain the process of freezing of meat and likewise understand the events that follow upon thawing.

3 Freezing Methods

Contact chilling to freezing temperatures is often done by a machine called a **plate freezer** (figure 41). In it sachets of soft (essentially shapeless) products such as deboned meat can be clamped between refrigerated metallic plates. The plates are cooled by circulating refrigerant

within them and they in turn freeze the product. But this machine cannot be used to freeze bone-in products such as whole wings, whole carcasses, whole legs, etc because they have definite shapes and squeezing them between metal plates would damage them. Furthermore the frozen products emerge from the machine in the shape of slabs or bricks - with several pieces stuck together. So you essentially have **block-frozen products** and can sell them only to bulk users such as hotels, restaurants and catering establishments who then thaw entire blocks to separate the fused portions before cooking them.

Air blast freezing is done in batch **blast freezing chambers** or in continuous freezing tunnels or spaces. There are two variations to the latter. The first variation is called a tunnel freezer, in which carcasses are dragged in trolleys,



through a long chamber in which a rapid blast of very cold air flows. A freezing tunnel takes a lot of space, so to save space a variant known as the spiral freezer or spiral chiller was invented. In this, a specially designed belt spirals upwards within an insulated cylindrical or cuboidal space. The product enters at the bottom and moves slowly up to the top – counter-current to the flow of air - where it is taken off the belt. A variant in which products enter at the top and exit at the bottom is also available. The speed of the spiral belt is chosen to fix the dwell-time that would completely freeze the product. That is why it is important to feed uniform-sized products into a spiral freezer. In this respect tunnel freezers and spiral freezers are similar – the dwell time being fixed, the heat load and product dimension must remain constant, or in other words, in tunnel freezers also, all trolleys must carry the same payload composed of similar sized products. Spiral freezers simply do not have the power and dwell time to freeze whole poultry carcasses. The commonest freezing facilities you will encounter in India is the batch blast freezing chamber. This has been covered in Section 13.2.

The last freezing method employs liquid carbon dioxide or liquid nitrogen as the cooling medium and is called **cryofreezing**. The “**cryo**” process is always meant for freezing with such gases – it is not employed in primary cooling. Why this method is never suitable for the poultry industry will be evident from the fact that with liquid carbon dioxide and liquid nitrogen which are the common cryofreezing liquids, energy cost is 4.5 and 17.5 times, respectively, that of mechanical freezing²⁰.

Although very energy efficient, tunnel freezers are not common in India. And spiral freezers are typically used for freezing burger patties, grilled poultry wings and poultry drumsticks in the RTE industry. For those who wish to source tunnel freezers for freezing whole poultry carcasses or portioned poultry, refer to the vendor database on this website. Readers desirous of learning more about tunnel freezing and why they have not become popular in India, may consult Aptec by e-mail – the subject is too specialized for coverage in this Handbook.

4 Immersion Chilling

Seven methods may be used for primary chilling, i.e. to bring the temperature of a poultry carcass down to around 4°C. These are:

- Leaving carcasses in a refrigerator at close to the target temperature of 4°C.
- Immersing the carcasses in a **static tank** containing a slush of cold water and ice.
- **Paddle** freezing in chilling tanks of vintage design.
- Immersing the carcasses in a screw chiller with cold water and ice.
- Chilling carcasses in an air tunnel after exposing them to a fog of water to form an icy crust (FAC).
- Hybrid chilling – first in a screw chiller, next in an air tunnel.
- **Evaporative** air chilling (EAC) by dragging carcasses on a conveyor through chilled air and periodically spraying them with water or dipping them in tanks of water.

Of these the first is entirely unsuitable because the process takes too long and in that period the carcass may be degraded by microbes. Although entailing the lowest capital cost, the static bath solution is inefficient. Firstly, since carcasses float in water (because they have nearly the same density as water), they do not make optimum surface contact with it. Secondly, this method does not afford a means of washing the carcasses. Finally this method gives variable results – because (a) the amount of ice in the bath reduces over time, (b) sunken carcasses cool more than those on top, (c) the cooling medium gets progressively contaminated with debris and finally (d) there is no cross-current cooling - in fact there is no flow at all.

The paddle chilling tank was the next to be invented. In this design some of the shortcomings of the static bath were remedied because the paddles agitated the bath and caused some circulation. This design was soon overtaken by the screw chiller design which is covered next. In this design a spiral screw propels carcasses forward so that all of them experience identical dwell periods and pass through a counter-current of water. At the end of the process carcasses are automatically removed from the bath by a windmill unloader - a standard feature in all modern screw chillers. Study figure 15 to familiarize yourself with the standard features of a screw chiller. The remaining three methods of chilling are covered later in this Chapter.

5 Immersion Chilling In A Screw Chiller

The first practical screw or spin chiller design was placed on the market by Morris and Associates of USA over half a century ago. Figure 10 shows several views of their machines. The main features distinguishing their initial



design were counter-current flow, an optimized fabrication design of the spiral screw, a modular structure and choice between an integral or independently driven windmill un-loader. Over time, major poultry machinery manufacturers adopted this design and modified it to suit their needs. So variations of this basic design continue to be available from the principal poultry slaughter-line vendors today. Some of the important variations are discussed in this Chapter. Besides principal poultry slaughter-line vendors, Morris and other specialists have in recent years sought to enter the immersion chilling sector as specialists, with product offerings limited to the business of immersion chilling. Some of their innovative (though not necessarily advantageous) offerings have been evaluated here.



Figure 10 Views of screw chillers produced by Morris And Associates. The picture in the middle shows the original design while the one on the left shows an early version of the one on the right – which is discussed along with its cross section in figure 16. These pictures have been taken from the website of the company – <http://morris-associates.com>

5.1 Chiller Capacity & Efficiency

In immersion chilling best results are obtained by (a) increasing the duration of immersion, (b) lowering the temperature of water used for chilling and (c) improving contact between carcasses and water. We call these **intrinsic factors** because these are physical and engineering factors, well under control of the machine designer and unrelated with bird size and market conditions. Proper consideration of these intrinsic factors will result in a good engineering decision about the chilling system for your plant.

And yet, a good engineering decision does not necessarily mean a good business decision. Factors related to the range of bird sizes you propose to slaughter, your proposed product mix and market conditions that influence the range of bird sizes also need to be factored in. These are **extrinsic factors** that determine your choice and configuration of chilling system. We will return to extrinsic factors in Sections 7.1 and 10.4 of this Chapter. For the moment we will return to the three intrinsic factors enumerated above.

5.1.1 Duration Of Immersion Or Dwell Time.

It is possible to get the best chilling performance from your screw chiller (water temperature, flow rate, ice quantity, bird size and BPH being constant), by prolonging the duration for which carcasses remain in the bath. This is called their **dwell time**. Typically good screw chiller line-ups for your plant's capacity will allow you to reach over 35-45 minutes of dwell time and with extra long chillers you may reach 60 minutes. Significantly longer dwell periods may result in excessive water pick-up which has its own implication, which we will revisit shortly. Meanwhile the relationship between dwell time and chilling performance for different carcass sizes is available from table 11.

It should be clear from this table that a dwell time in simple 2°C water immersion is not sufficient to bring carcass temperature down to the prescribed 4°C in 35-45 minutes. We simply must add flake ice to the cooling bath to achieve this. How flake ice achieves this, is explained later in this Chapter. For the present we shall understand the impact of chiller diameter on its capacity.

To increase capacity in BPH and dwell time you can opt for either longer or wider chillers. Capacity and dwell time have a **linear relationship** with the length of a chiller, but an **exponential relationship** with diameter of the chiller. For instance if you double the length of the chiller from 6 metres to 12, you either also double the dwell time for the same capacity in BPH or double the capacity in BPH while maintaining the same dwell time.

Something different happens when you increase the diameter of the chiller. For the hemi-cylindrical shape of a typical chiller, capacities are related by the formula d^2/D^2 where d is the diameter of the narrower chiller while D



is the diameter of the wider one. Thus, with an increase of 50% in diameter (from 1600 to 2100mm), the volume of a metre of 2100mm diameter chiller increases by 72% over that of a metre of 1600mm diameter chiller!

$$[2100 \times 2100 / 1600 \times 1600 = 4.41 / 2.56 = 1.72]$$

Time	Gram	1.000	1.100	1.200	1.300	1.400	1.500	1.600	1.700	1.800	1.900
0		42,0	42,0	42,0	42,0	42,0	42,0	42,0	42,0	42,0	42,0
5		37,0	37,1	37,2	37,3	37,4	37,5	37,6	37,7	37,6	37,7
10		33,6	33,8	34,0	34,2	34,4	34,5	34,7	34,8	34,8	34,9
15		30,4	30,8	31,1	31,4	31,7	31,9	32,1	32,3	32,4	32,5
20		27,1	27,6	28,1	28,5	28,9	29,2	29,5	29,8	30,0	30,2
25		23,9	24,5	25,1	25,7	26,1	26,5	26,9	27,3	27,6	27,8
30		20,9	21,6	22,3	22,9	23,5	24,0	24,4	24,8	25,1	25,4
35		18,2	19,0	19,7	20,4	21,0	21,5	22,0	22,4	22,7	23,0
40		15,9	16,6	17,4	18,0	18,7	19,2	19,7	20,2	20,5	20,8
45		14,0	14,6	15,4	16,1	16,7	17,1	17,7	18,2	18,4	18,7
50		12,2	12,9	13,6	14,3	14,9	15,4	15,9	16,4	16,7	17,0
55		10,7	11,3	12,1	12,7	13,3	13,8	14,3	14,8	15,1	15,4
60		9,3	10,0	10,7	11,3	11,9	12,4	12,9	13,4	13,7	14,0
65		8,2	8,8	9,4	10,0	10,6	11,1	11,6	12,1	12,4	12,7
70		7,1	7,7	8,3	8,9	9,5	9,9	10,4	10,9	11,2	11,5
75		6,2	6,8	7,4	7,9	8,4	8,9	9,3	9,8	10,1	10,4
80		5,5	6,0	6,5	7,0	7,5	7,9	8,4	8,8	9,1	9,4
85		4,8	5,2	5,7	6,2	6,7	7,1	7,5	7,9	8,2	8,5
90		4,2	4,6	5,1	5,5	6,0	6,3	6,7	7,1	7,4	7,7
95		3,7	4,1	4,5	4,9	5,3	5,7	6,1	6,4	6,7	7,0
100		3,2	3,6	4,0	4,4	4,7	5,1	5,4	5,8	6,1	6,3
105		2,8	3,1	3,5	3,9	4,2	4,5	4,9	5,2	5,5	5,7
110		2,4	2,8	3,1	3,4	3,8	4,1	4,4	4,7	4,9	5,1
115		2,1	2,4	2,7	3,0	3,4	3,6	3,9	4,2	4,5	4,7
120		1,8	2,1	2,4	2,7	3,0	3,2	3,5	3,8	4,0	4,2
125			1,8	2,1	2,4	2,7	2,9	3,1	3,4	3,6	3,8
130				1,9	2,1	2,4	2,6	2,8	3,1	3,3	3,4
135					1,9	2,1	2,3	2,5	2,7	2,9	3,1
140						1,9	2,0	2,3	2,5	2,6	2,8
145							1,8	2,0	2,2	2,4	2,5
150								1,8	2,0	2,1	2,3
155									1,8	1,9	2,0
160											1,8

Table 11 Time, carcass weight & temperature relationship. From Peter Kragtwtijk, refrigeration expert at Meyn. Time is in minutes, carcass weight (top row) is in grams after evisceration and carcass temperatures in the body of the table are in degrees C. Initial carcass temperature is taken here at +42°C. It is assumed that the chilling medium is at between 0°C and +2°C.

Normal chiller shell diameters vary between approximately 1200mm and 2100mm, with the lower end being mainly meant for chilling of edible giblets, hocks and portions. For chilling whole carcasses shell diameters range between 1600 and 2100mm. Wider shells beyond 2100mm (typically 2440, 3048 and 3658 mm) are available from Morris²¹ and others. These wide-bodied design have been influenced by the availability and ease of transport of extra-wide SS stock at competitive prices from rolling mills to these chiller fabricators.

Volume for volume, when their capacities are compared with 2100mm shell diameters, extra-wide shell diameters are cheaper to manufacture and therefore when you compare commercial offers for different sizes of chillers, this relationship ought to broadly reflect in the price bids. But any savings in manufacture may be offset or even exceeded by the additional cost of packing assembled extra wide-bodied chillers and transporting them from the place of fabrication to your plant site and into your plant building. Remember, standard transport containers have an internal width of 2400mm. Anything above this needs non-standard packing, transport and handling systems.

When choosing large diameter chillers you should remember that many bridges and roads in India remain incompatible with extra wide vehicles. Take a map and note all nominal road widths, bridges, culverts, tunnels, bends in roads, and position of transmission towers, lighting, telephone poles and other structures along roads between the port of arrival and your plant site before choosing extra-wide and extra-long loads. Then take your car and drive through the chosen route and evaluate all critical locations. Find out the additional cost this entails and only then make your choice.

Finally also remember that as your plant expands, you will need to add sections to lengthen your chillers. Large diameter chillers occupy less floor space (remember the exponential relationship!), but unless the building is wisely designed and constructed, it is likely that you may run out of space to manoeuvre new machinery into place. So it is smart to always opt for the largest diameter chiller at the outset, but consistent with the caveat to limit the width choice to local transport infrastructure and the width of the door and aisle within your plant building. We believe that restricting your choice to within 2400mm diameter is a safe strategy. Refer to Chapters 3 and 4 where case studies relating to these have been discussed.

5.1.2 Rotation Speed Versus Chiller Size

You can maximise the dwell time by reducing the rotation RPM of the screw with the help of the mechanical or electronic speed regulation which any decent machine ought to have. However there are limits to which you can



reduce the rotation RPM. To **discover these limits of your machine**, start with a given RPM setting and count the number of carcasses being dropped into the chiller and also the number discharged by the unloader within a reasonable time period, say 10 minutes. Make sure that the bird unloader or hock cutter, (depending on the configuration of your line) is performing properly and not missing carcasses. Perform the counting operation by placing one person at each end and counting for a 10 minute period, both persons beginning and ending the count on cue. Begin your counts starting from zero. Like this: 0 1 2 3, instead of 1 2 3.

The number of carcasses by your count must be a trifle more, say one tenth of the BPH at which your evisceration department is operating. This is because in a good plant every succeeding section must diligently be set at a higher BPH than its preceding section so as to avoid possible product pile-up or accumulation at transfer points!

Now lower the screw RPM slightly and count again and note down the new carcass entry and removal rates. Also observe the density of carcasses in the chiller and the number of spillovers in each block as it progresses towards the discharge end. Continue repeating the counting process with each lowering of RPM till you notice that carcasses are reasonably tightly packed within the chiller. At this point more carcasses should be removed during each 10 minute interval than the number of carcasses coming in. When the screw RPM of your chiller has been set at a speed at which the carcasses are **reasonably tightly packed** in the operating quadrant of the chiller, the removal rate of carcasses is somewhat higher than the addition rate of carcasses and there are not too many carcasses in the other - safety quadrant, then with this RPM setting you have maximised the dwell time within that chiller for a given carcass size.

During regular operation of the plant, if the screw RPM falls below this setting, you are effectively allowing the screw chiller to accumulate more and more of your production as your shift progresses. Soon, a time may be reached when the mechanical load built up by this accumulation of carcasses will cause severe and irreversible structural damage to the shell of the screw chiller and of carcasses trapped within!

5.1.3 Drive Speed Regulation.

Two types of RPM regulation may be found on screw chillers. The older designs were mechanical, but they have now been replaced universally with electronic regulators called frequency controllers (VLT). If your old chiller's mechanical regulator fails, do not attempt to repair it. Just mechanically couple the drive motor shaft with the screw shaft in a 1:1 ratio and wire an electronic regulator in the drive motor circuit.

5.2 Modular Versus Welded Construction.

The best chillers are manufactured in modules of 3000 and 6000mm nominal lengths. This is for ensuring consistency with 20 ft and 40 ft shipment containers, normal door dimensions in your plant building and proper orientation and positioning of new screw chiller modules into process areas within your plant. Modules are then assembled at site. Modular design calls for absolute dimensional consistency with the help of CNC machinery during manufacture.



Figure 12 These pictures of locally fabricated chillers were taken by the Author. They show welded end-plates. Note the tack-welded braces on the end-plate. Tack-welding is not acceptable for machinery for the food processing industry. If braces are added for strengthening the end-plate against buckling, they should be seam-welded. The brace consists of an SS channel with open ends which would allow debris to accumulate!

Since small local fabricators do not have access to CNC machinery, they tend to produce all-welded, mono-block, ready-to-install chillers that cannot be expanded at site. This is true not just for local fabricators but also for Chinese ones that come at 'attractive' prices. When you purchase these machines, there are only two ways you can expand plant capacity. The first involves progressively cascading or dropping carcasses from one chiller to the next. But there is a limit to this because with every successive stage of cascade, the height difference between chillers must be approximately 500mm. So it is impractical to achieve more than one cascade-drop stage in a normal processing building. The other way is to scrap or sell existing machines and instal newer, longer machines. But this method might cause an interruption in production and in the interim you would lose customers.



Modular chillers consist of a hemi-cylindrical shell with end-flanges, a screw (which may be with or without an integral windmill unloader), a drive with gearbox and mechanical or electronic speed variator, two end plates with bearings to fit onto the end flanges of the shell and a blower to deliver compressed air to the bottom of the water bath. Figure 15 shows such a construction.

Sections to be added to existing modular chillers consist of a hemi-cylindrical shell with end-flanges, a screw of appropriate length, a bridge with bearing to be bolted where the screws and shells are joined together, additional machine legs and additional blowers for every 6000mm increase in overall chiller length. There is usually no need for an additional drive. To install an extension, you unbolt the end plate and end legs of the existing machine; position the new shell and screw between the now unbolted end flange and machine, raise it and fix the new legs and shell flanges together with the bridge and bearing, reposition the end plate by joining it to the now new end flange and align everything to ensure that the lengthened screw runs true. Then you connect the additional blower. If the earlier screw had an integral unloader, it is placed adjacent to the end-flange and you are good to go!

In effect, if you purchase and install a 6000mm mono-block-welded chiller in phase one of your plant capacity, you can at best install just one more 6000mm chiller in subsequent expansion stages. On the other hand, had you opted for a modular chiller at the outset, you could progressively add sections to it, to reach as much as 18,000mm, and yet be able to drive the screw with a single (existing) drive motor-gearbox combination.

5.3 Single Or Ganged Multiple Bath Configuration

Your chiller configuration may consist of a single chiller having a single water bath or it may consist of two or more water baths. When the arrangement consists of two baths, the first is referred to as the pre-chiller. From the first bath carcasses are lifted out and dropped into the second bath by a fixed un-loader. The two baths are generally held at different temperatures – the first at 12 or 14°C and the second close to 0°C (chilled water supplied at 2°C and flake ice added to bring the bath temperature close to 0°C). Why should you prefer a two bath chiller configuration?

Three factors - hygiene, economics and water pick-up - come into play in the decision to opt for a two bath configuration instead of a ganged two bath chiller. And while we discuss these factors here and elsewhere in this Chapter, it is important to consider water pick-up, which is best in the pre-chiller (see figure 20) and which increases subsequently up to a point, depending on the dwell time. The longer your dwell time, the higher your water pick-up. Water pick-up may be viewed as desirable or undesirable from the product quality and ethical points of view depending on whether this is carried to an extreme level or restrained to a level consistent with the aim to produce succulent and tender poultry meat. The subject is covered in detail in Chapter 6 which discusses the biochemistry of poultry meat. For the moment it should suffice to hold the thought that during processing, it is important and desirable to allow poultry to pick up some quantity of water to compensate for the desiccation that occurs during *rigour mortis*. Different limits have been prescribed for the quantum of water pick-up as shown in table 19.

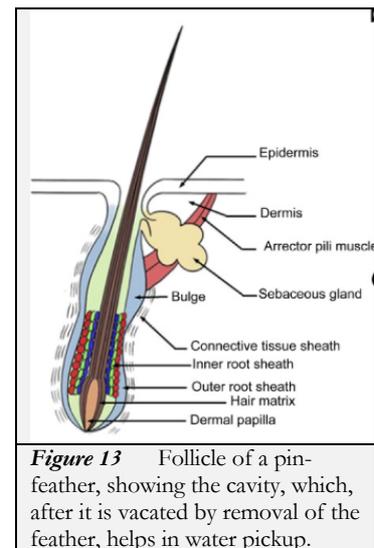


Figure 13 Follicle of a pin-feather, showing the cavity, which, after it is vacated by removal of the feather, helps in water pick-up.

Given the same overall dwell time, how a two bath configuration facilitates water pick-up is explained when we consider the behaviour of feather follicles on a carcass. Feather follicles are analogous to hair follicles on our skin. Figure 13 shows a feather follicle. When you de-feather poultry, the feather follicles still retain muscles which are autonomous and are capable of snapping shut or remaining open: depending on the temperature that the skin experiences. This muscle remains active for some time following the bird's death.

A typical two bath configuration consists of a 3000mm pre-chiller bath followed by a 6000 or 9000mm chiller or a 6000 pre-chiller followed by a 12000 or 15000mm chiller bath, depending on plant capacity. Since these baths are arranged serially and are of identical shell diameters and screw pitch, the screw RPM in the pre-chill bath must be nominally between two and five times higher than the RPM in the chiller in the above examples. When this is so, the dwell times must vary roughly inversely to the lengths of the chiller baths.

When carcasses enter the 12 or 14°C bath in the pre-chiller, the feather follicles remain open and pick up water. Since water at this temperature is cheaper to produce than water at 2°C, we achieve economy by opting to



maintain this bath at 12-14°C instead of maintaining it at near 0°C. Also, as table 21 shows, maximum water pick-up occurs when product and bath are still relatively warm which is the condition favouring pick-up. But we certainly achieve some degree of cooling here because, remember, the carcass is at this moment at a much higher 41°C. Besides this, because this water is cheaper to produce, we deliberately maintain a more rapid flow rate in the pre-chiller, by doing which we achieve a higher level of product wash and slightly more efficient heat exchange. On being dropped into the next chiller bath at a temperature of 2°C, muscles on the feather follicles of the dropped carcasses experience a thermal shock and snap shut. This causes the picked-up water to be retained.

In conclusion, besides achieving a good wash, water pick-up and some heat exchange, **a two bath system facilitates water pick-up**. With a two-bath arrangement, a water flow rate of 1.8 litres at 12-14°C per kilogram of carcass and a water flow rate of 0.7 litres at 2°C per kilogram of carcass is maintained in the first and second baths respectively. Taken together, these flow rates conform with the wash-water standard of 2.5 litre per kilogram of carcass weight.

Picked-up water may be retained for a period of time depending on several factors, such as (a) time, (b) duration, (c) speed of restoration of pre-rigour conditions, (d) temperature, (e) method of handling, (f) whether or not the product is subsequently slated for freezing or sale as fresh-chilled and (g) whether or not the product is deskinning and portioned. Water pickup may, in the extreme case, be as much as 12%²² of the carcass weight or at the desirable level as low as 2 - 4%. Consequently the quantity of drip loss will represent both the excess pick-up as well as the migration of this water back into the muscle mass to restore the initial succulence of meat following the end of rigour conditions. A small amount of water pick-up may also occur during air chilling, both FAC and EAC. when excess fogging or spraying is done before the carcass enters the tunnel, the feather follicles pick up water and muscles around the follicles snap shut in the tunnel to retain the pick-up.

Any drip-loss occurring after the product is packed leaves a tell-tale quantity of pink water in the sachet. Companies in USA such as Bells & Evans, which were among the first in that country to adopt air chilling, make a virtue of their business decision. They claim that with conventional (immersion) chilling systems, chickens absorb up to 12% of their body weight in added chlorinated water and that this water “weeps” out of the meat and is trapped in the “diaper” you find in most fresh chicken packaging²³.

To sum up, as long as the product picks up some water and loses only a small quantity of it, poultry meat retains the possibility of regaining its succulence as rigour conditions subside. Therefore **limiting, but not eliminating water pick-up and reducing drip loss are both desirable from a quality point**.

5.4 Fixed Versus Independently Driven Unloader

Screw and un-loader are usually mechanically coupled together and driven by one motor-gearbox combination to save overall cost. This is shown in figure 15 (right side). A better design has an independently driven un-loader. With the un-loader being independently driven, it is possible to set the rotation RPM of the screw **independently** of the unloader. Why is this helpful?

Ask yourself what role each is required to serve. The screw should spin slowly to maximize product dwell time so as to achieve the maximum chilling effect, but the unloader must spin faster to ensure that the carcasses appearing within its vicinity are removed as quickly as possible so as to prevent pile-up and mechanical obstruction leading to product and machine damage. So when you want to get the maximum performance from your machine, you should opt for independently driven un-loader, except in the case of the pre-chiller in a multiple chiller arrangement.

5.5 Ganged Drive Chillers & Dwell Time Implications

So far we have already noted the superior performance of a two bath system and independently driven un-loader. However, a ganged two-bath machine with just an additional in-built partition and unloader, costs considerably less than two independent chillers of the same overall size to fabricate. So some vendors started offering a two bath ganged chiller with a partition and a single ganged drive as a substitute. Here a single long shell is partitioned into two baths with the first bath limited to a few metres down from the input end and a single drive shaft that runs through the machine. When carcasses reach the partition they are lifted up by a built-in un-loader and tumbled into the next partition. In such a system, the dwell time in the two baths is strictly dependent on the ratio between their lengths. For example, in a 9000mm ganged chiller, the pre-chiller bath is 3000mm long and the chiller bath is 6000mm long. So the dwell time in the first bath is half that of the dwell-time in the second



bath. Here, because the vendor has saved on the cost of two end-plates, a drive-motor and possibly a blower, his system costs less than the cost of two independent 3000 and 6000 chillers taken together. But it compromises your choice and forces you to suboptimal performance for the entire life of the machine. Why?

Particulars	Calculations	Water flow
Water wash required/hr @2.5 litres per kilogram of carcass	2.5x1.6x2500	10,000 litres
Of which water at 12°C flow @ 1.8 litre/kg of carcass in bath 1	1.8x1.6x2500	7,200 litres
And water at 2°C @ 0.7 litre/kg through bath 2	0.7x1.6x2500	2,800 litres

Table 14 Features of a 9000mm ganged screw chiller arrangement.

Assume that you chose a 9000mm system for 1600 gram carcasses at 2500 BPH, 12°C water in bath 1 and 2°C in bath 2, and dwell time, set for a total of, say, 39 minutes to be divided into 13 minutes in bath 1 and 26 minutes in bath 2. You are now stuck with the result summarized in table 14.

Now one day you receive heavier birds with carcass weight of 1900 grams. Your experience tells you that now your carcass will need 50% extra chilling time. But to do so, the 58.5 minutes dwell time in the chilling department gets either wasted in bath 1 where a dwell time of 19.5 minutes is un-necessary (you could have managed with around 6-10 minutes), and a dwell time of 39 minutes in bath 2 is insufficient. If each bath had its own drive, you could have allowed 6-10 minutes in bath 1 and the remaining time in bath 2. With this vastly increased dwell time in bath 2, you could have better utilised the chilling capacity of bath 2.

From the above discussion it is evident that a ganged two bath configuration incorporating a single drive is a decidedly inferior design. When such a ganged chiller is offered by your vendor, opt either for a single chiller system incorporating the combined volumetric capacities of the two baths on offer, or for two single stand-alone chillers - your budget permitting. Remember, increase in capital cost is a one-time problem which you can overcome. Besides it gives you the benefit of depreciation which is a tax saver, but an increase in operating cost is a permanent burden which can render your operations unprofitable and with no solution in sight. But if you had chosen the single combined volume option of chiller at this stage because of budgetary constraints, you could, upon expansion, remedy your past choice by purchasing a second stand-alone chiller and thus ultimately achieve a two bath independently driven chiller combination. With a rapidly expanding market for processed poultry in India, such an opportunity for expansion may come around within a year or two.

Summing up, the previous sections proposed that provided your plant capacity is large enough to warrant several sections of 3 metre length screw chilling, say 9000mm, the better choice for you is to go in for a two bath system, say, of 3000mm and 6000mm, with each chiller being independently driven, and the 6000mm chiller having an independent un-loader drive. But if you have budget constraints, dropping the independently driven un-loader feature would have the least negative consequence for you.

5.6 Fill-level, Functional Quadrant & Surge Equalization

Figure 15 shows the cross-section and plan of a standard screw chiller. Several things become apparent from the design. Carcasses tend to remain in one **quadrant** - the one over which they are dropped, which in this picture is the left quadrant, and will likewise also exit from this quadrant. To make some, or many, of the carcasses wander off into the right quadrant, would need some unusual force. Such a force could arise because of crowding of carcasses in the left quadrant. Another force at work is the constant upward welling of air bubbles, but this force acts randomly and can not cause sustained lateral movement of carcasses. In the end, bereft of any lateral force, carcasses will be propelled forward (in the case of this picture, towards the reader) and be lifted out of the bath by the un-loader.

The structure and pitch (flights are spaced 800mm apart) of the screw ensures that **carcasses move in blocks**, not as a continuous unbroken stream. They remain in their quadrant and within their block until they reach the discharge end at a speed defined by the RPM of the screw. The chiller **appears** to be a device designed for moving a **continuous stream** of carcasses, but in effect it moves **discrete blocks** of carcasses. One may now ask, surely, if we were to use both quadrants, could we not effectively double the chiller’s capacity. So why do we use only one quadrant?

When carcasses are dropped over the left quadrant, most remain in it, but when this quadrant gets overcrowded, some spill **under** the central drive shaft into the right quadrant. If the water level is held somewhat higher than the central drive shaft, some carcasses could likewise slip **over** the shaft into the right quadrant. Spillage over the shaft moves carcasses **backwards** while spillage from under the shaft moves carcasses **forward**. If the water



level is maintained well above the central drive shaft, the slip gap gets widened. Then there could also be slippage of carcasses through the slip gap, in which case they would move **backwards**.

Now let us consider what happens in practice. The rate at which carcasses are dropped into the chiller is dependant on the line speed in the evisceration department. Assume that both the EV line speed and the RPM of the screw are matching and set correctly with respect to each other. Now only a given number of carcasses will drop within a given time and will form blocks in the chiller. And given a certain uniform carcass size, each block will equal the next in volume, number of carcasses and total weight. But a number of conditions may vary the next future block by (1) number of carcasses, (2) their collective weight and (3) total volume to be occupied. This undesirable difference in block parameters will upset the balance and may occur for any of four reasons:

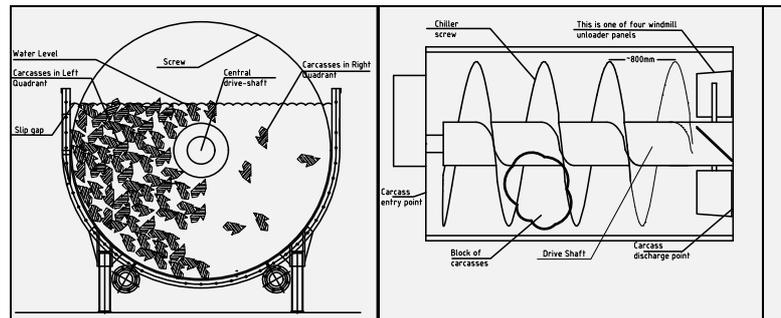


Figure 15 Left picture shows the cross section of a screw chiller viewed from the discharge end. Right picture shows a 3000mm screw chiller viewed from the top. Note the different parts of the chiller and the zone which designates a block of carcasses.

- 1) You increased the line speed in the EV department but forgot to increase the RPM of the unloader to match. This caused an over-crowding or pile-up of carcasses in the next block in the left quadrant. Because of this some carcasses within it show signs of physical damage.
- 2) When you were twiddling with the setting of the windmill unloader panels to optimize its performance, you inadvertently set it at a less efficient angle and the extraction rate has reduced to such an extent that the number of carcasses falling in is significantly more than the number of carcasses being extracted. This has resulted in over-crowding or pileup.
- 3) Today you are now running the plant with significantly larger carcasses. Since your chiller RPM was earlier optimised for smaller carcasses, even given that you have not increased the EV line speed, the larger carcasses are occupying more volume and this has resulted in over-crowding or pileup.
- 4) There are large variations in carcass sizes within a given block in the chiller. In other words when you process birds which are neither sexed at the farming level, nor raised in EC sheds - as they are in India, there are large **size variations within flocks**. Even if you have already ensured that the above three factors are attended to, and your screw and unloader speeds have been carefully set, carcass size variations within a block severely underscore the importance of safety spillover mechanism **within** a block of carcasses delimited by two adjacent flights of the screw. The chiller may now exhibit **sporadic** and inexplicable over-crowding or pileup or fortuitous spill-over if the water level is set high and spill gap is wide enough.

Worse yet, it is possible that not just one but maybe all the above four factors may simultaneously come into play. What is the worst that could happen? Crowding of carcasses would reach a level at which the screw will force carcasses against the discharge end flange and set up a tremendous hydrostatic pressure against it. This pressure wave would then travel backwards and eventually result in tremendous pressure against the end plate at the receiving end and cause it to buckle. This will damage both the machine and carcasses.

This is not a hypothetical scenario. This author has had to perform difficult field repairs in just such a case around 2002 when a smart-aleck plant supervisor tried to “improve” the dwell time of his machine well beyond its design limits by secretly tweaking the un-loader plates.

A similar situation was slated to occur around 2016, when, for the proposed expansion of a 2000 BPH plant, the plant manager at another facility insisted that the chiller needed no extension since it was using only one quadrant while a virtually vacant quadrant was already available for doubling its capacity. These safety features were explained to him but his mind was made up. When he was asked by this Author to take personal financial responsibility for performance and personally underwrite repairs, he reluctantly withdrew his argument. But his



mental block persists and he remains unconvinced to this day! Perhaps the detailed explanations given here, complete with illustrations, may help change his mind.

How this safety feature works is understood by imagining how carcasses slip over, or under or through the slip gap when overcrowding occurs. If the water level is maintained somewhat above²⁴ the central drive shaft as shown in figure 15, some carcasses will spill over it and into the right quadrant. If the water level is flush with the central drive shaft-line, carcasses would tend to slip under it and into the empty right quadrant. In both cases the block structure would be retained within the confines of adjacent screw flights. Spillover into the right quadrant relieves the hydrostatic pressure in the left quadrant. Therefore a relatively empty right quadrant for each **block** of carcasses functions as the safety surge space and prevents buildup of destructive hydrostatic pressure in the machine. Remember, it functions as a safety measure, not just for a continuous stream of carcasses, but even for discrete blocks of carcasses.

How can an independently driven un-loader help? By allowing spillover under certain conditions by any of the three mechanisms mentioned above, you would be exceeding the discharge capacity of the fixed un-loader and compromising the built-in safety feature. On the other hand, if your un-loader has an independent drive, and you carefully monitor the transit rate of carcasses when you set the speed of the un-loader, you may compensate for the slight capacity enhancement created by carcasses in the right quadrant. But were you to fill the right quadrant entirely, you would once again lose the surge safety feature entirely.

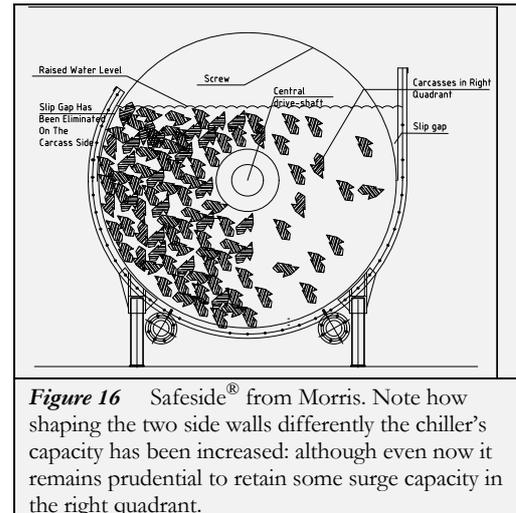
Now we will examine the innovation by Morris. We can imagine that for years designers at Morris may have sought to raise the capacity of their machine and have had to contend with slippage arising out of an enlarged slip gap. See the left picture in figure 10. All sidewalls have been raised well above the drive shaft, so the water level in this machine would be high enough to widen the slip gap and freely allow carcasses to slip back or ahead when they got packed too tightly in a block. The safety surge space on the right side may then have compromised on safety by admitting too many carcasses into this volume. Raising the side walls on both sides vertically upwards increased the slip gap and forward propulsion of carcasses suffered because they no longer moved in blocks – they could now easily slip past the enlarged slip gaps and destroy block formation. Further still, the un-loader, which was probably angled to lift only a certain proportion of carcasses, would now work inefficiently, resulting in a pile-up at the un-loader end. All this makes it clear that the only guaranteed way to maximise the volumetric utilisation of a screw chiller is to enclose the screw in a **tubular shell** and allow it to move carcasses within that carcass-filled tube. But this would not work because it would make cleaning the machine a nightmare!

Eventually Morris discovered a way to solve this problem with their Safeside[®] design which is shown in figure 16. In this design only the right side wall has been raised upwards. While the left side wall also rises, but it curves around the screw. This allows one to raise the water level, without carcasses slipping past the slip gap on the left side. The straight side wall on the right side, on the other hand, leaves a larger slip gap which allows only a few carcasses to slip because there is a lower density of carcasses on the right side in any case. More of the left quadrant is now occupied by carcasses, the capacity improves, and only a smaller safety space remains because the right quadrant is partially filled. But all these changes make it incumbent on the plant supervisor to calibrate the screw and un-loader RPM carefully in the manner described in Section 5.1.2.

Morris additionally offer some automation so that the safety features do not get fully compromised. However to save money you may not have purchased these optional automation features and if so, then the safety of your system depends entirely on meticulous limitation of the RPM as described in Section 5.1.2!

5.7 Closed Circuit Heat Exchange In Red Water Chillers

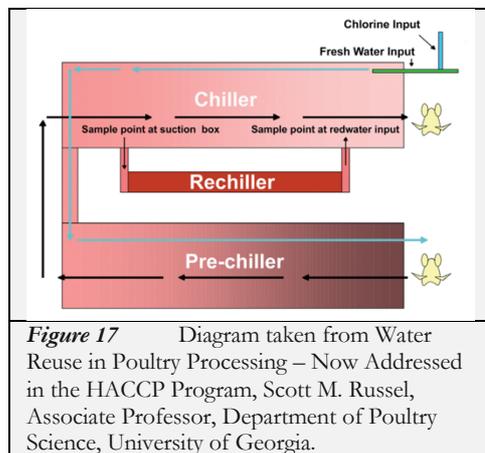
Some companies offer water re-circulation systems with their screw chillers. In this arrangement the discharged water is passed through a refrigeration heat exchanger to form a part of the heat exchanger-water chiller configuration. Discharged water is cooled back to around 2°C and reintroduced into the screw chiller in a closed



loop. In such a closed loop circulation arrangement, after a very short time the water contains enough blood to justify the name (red water chilling system) given to it.

Such a system is available from Morris with a refrigerant evaporation temperature of 6.7°C. This would make it somewhat different from the typical red water chiller whose objective in incorporating a heat exchanger into a closed water circulation system appears to be to reach extremely low carcass temperatures- say close to 2°C. However it shares some of the undesirable features of a red water chilling system which go against the FDA regulations as discussed below. What is wrong with such arrangements?

In a letter dated January 19, 2005, the USDA-Food Safety Inspection Service (FSIS) indicated that if water is to be reused in a poultry processing facility, then this reuse water must be accounted for in the plant's HACCP program. To prevent reuse of bad chill water (including chiller red-water re-chilling systems and recirculated warm water in a scalder), the USDA enacted new regulations in 9 CFR 416.2 (g) which mandates that measures be taken to reduce physical, microbiological and chemical levels for reuse. This can only be achieved by ultra-filtration of the recycled water to remove tissue debris and microbiological methods such as ozonation being made part of the recirculation circuit (i.e. placed within the re-chiller circuit shown in figure 17). Sample points in the circuit are to be considered critical control points (CCPs). Removal of microbes is an obvious objective and conservation of water equally desirable. But why does failure to remove tissue debris and microbes matter?



With red water chillers it is possible to ship out fresh chilled poultry carcasses at temperatures as low as +2°C or even closer to freezing point, which would mistakenly appear as a great achievement for the operation, firstly by lowering the product temperature thus extending the shelf life and secondly by conserving water. However, the emerging product gets so heavily loaded with temperature-inactivated pathogens that as soon as the product reaches the retail outlets and the product temperature rises above +4°C, it deteriorates more rapidly than poultry produced in plants that follow 9 CFR 416.2 (g).

To understand this, we must note that as the concentration of tissue debris rises, more and more chemically available chlorine gets locked up in the cellular debris and ceases to be bio-available for control of living microbes. Worse still, any chemical assay carried out in the chlorine dosing system would show that everything was in order and this would throw the management off the lead that there could be a relationship between the red water system and rising customer complaints. Since red water chillers fail to remove tissue debris, by definition, such chilling arrangements fail the physical removal condition, cause the operation to lose control over the quantity of chlorine in the medium and consequently on reduction of potentially active microbes.

5.8 Other Concepts & Features Of Screw Chillers

When the screw auger is tight against the shell, it allows less wash back of chilling water. This is reported by CLP Industries Co. who place strengthening ribs every 5 ft along the shell's length in their **fatcat** chillers to maintain a small gap between the shell and auger. Also, in this model interruptions in the screw flights allow ice to pass through, but retain carcasses (figure 18). Large systems supplied by this company has three chillers in series, with each incorporating two compartment baths with arrangements for flake ice dosing in each bath. The role of compartments in each chiller and that of ice dosing at each stage indicates poor understanding of the principles explained in this Chapter. STAL (Schladzalnink Slimakowy Dribou) on the other hand, features an improved unloader design which restricts carcasses from falling back into the bath. While distribution of carcasses to both sides of the drive axis to increase capacity is a central theme from Morris, they also offer some other features meant to achieve even distribution of carcasses using a series of pumps and sumps and a CIP feature. Chapter 4 explains how you can mount the blowers on the roof of the building instead of mounting them within the chiller room. This has the desirable effect of reducing noise in the workplace and using the compression power to properly direct movement of air within the plant.



5.9 Dosing Ice - Cold Water Is Not Enough

To ensure that the medium in the chiller bath remains close to 0°C, you need to add flake ice to it. Why must ice be added? Remember that when a gram of ice melts in the bath, it must draw 80 calories of heat energy from the bath water. This adds cooling power, far in excess of cold water itself and the process of melting ice clamps the bath temperature close to 0°C – far more effectively than mere water can (which in any case was introduced at 2°C anyway and rapidly warms up in contact with carcasses). Typically you need to add at most a quarter kg of ice for a kg of carcass to ensure this.

When the flaker is mounted above the chiller, to regulate the flow of ice into the chamber all you need to do is tweak water flow into the flaker with a valve. If water flow into the flaker is excessive, large quantities of ice will be dosed and some of the carcasses will carry ice within the body cavity. Then, when they are re-hung onto the weighing-sorting line, your weights will be incorrect.

Mounting the flaker above the chiller on the roof of the building is a far better method than having to shovel ice manually into the chiller from an ice store on the ground floor or erecting a steel platform within the chiller hall to mount the flaker on. If for some reason the flaker needs mounting on the roof at some distance from the chiller, in some processing plants people arrange an overhead sliding chute within the hall to direct ice into the chiller. This is incorrect as it allows ice to pick up heat, amounting to 80 calories, from the surrounding air. The arrangement then functions more as a room cooler than as a carcass cooler. Mounting the flaker on the roof calls for you to make the roof sufficiently strong to take its weight. This is one of the reasons we recommend an RCC slab roof over the primary processing part of the slaughterhouse. Chapter 3 explains this.

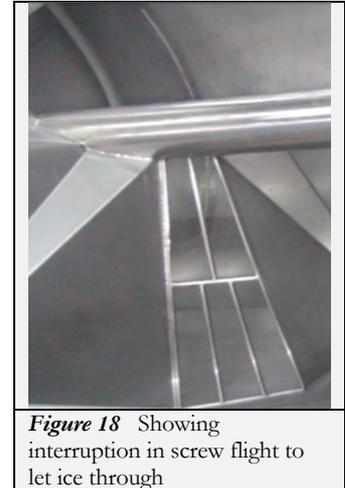


Figure 18 Showing interruption in screw flight to let ice through

Dosing of ice is best made close to the discharge end, approximately at 70% mark of the chiller's length measured from the carcass inlet end, on the carcass quadrant of the drive shaft (not the side where the surge quadrant exists). Ice should not be dosed in the pre-chiller. Flake ice is preferred over shell, tube, or crushed ice because flake ice melts more rapidly than all other forms.

5.10 Overkill With A Falling Film Chiller

There are limits to which fruit juices can be chilled by heat exchange using water as the chilling medium. And since you do not want to dilute the juice you cannot chill them by directly dropping ice. But even if you were to use water held as low as +1°C circulating within a heat exchanger, you cannot chill the juice down to 4°C because the temperature difference (ΔT) between the chilling liquid and juice is just too small. But because pure **propylene glycol** freezes at -59°C, by using its mixture with water as a secondary refrigerant in the heat exchanger, you could chill the juice down to +1°C.

Another method of chilling fruit juices down to +1°C is to employ a falling film chiller. In such an arrangement the juice is made to cascade over an open refrigerant-chilled plate. As the juice cascades down, some of the water within it evaporates and this chills it down to +1°C.

Would you recommend a falling film chiller for generating the ultra cold water of +1°C to improve the efficiency of screw chilling of poultry carcasses? Remember falling film chillers are expensive machines. Does the expense warrant the benefit of that extra 1 to 2 degrees centigrade advantage they provide over direct contact of the carcass with ice slush?

We think not! Poultry carcasses can be immersed in a slush formed by adding flake ice to chilled water coming from either an ice-bank tank or a plate heat exchanger, both of which are cheaper machines. And poultry carcasses can dwell comfortably in the slush, losing heat through direct contact. After all, unlike fruit juice poultry cannot get 'diluted' by coming directly in contact with this cooling medium! Alternatively, if the end temperature achieved by chilling carcasses in ice slush in a screw chiller does not satisfy you, and you prefer not to use a red water chilling system for reasons given above, a hybrid primary chill may be the best answer for you. See Section 11.



5.11 Dosing Germicide

Of all additives used in reduction of pathogens in the immersion chill stage, various forms of chlorine are most prevalent. Commercially available sodium hypochlorite (NaOCl) solution is the commonest additive for this purpose. It is available in various concentrations (ranging from 1 to 12.5% chlorine content) for use as a household bleach, industrial disinfectant, and a water treatment agent. In the liquid form it is often packed in cans or drums. Another related disinfecting agent is calcium hypochlorite, also commonly called bleaching powder, calcium oxychloride or chloride of lime. It is a white, granular solid with a characteristic chlorine odour and is used directly by sprinkling over roadside gutters and municipal garbage dumps as a disinfection agent. But as a germicidal additive in immersion chilling the sodium compound is generally more common.

Chlorine gas may also be directly used in immersion chilling. For this application, the gas is available in a compressed liquid form in half or one tonne mild steel cylinders. These cylinders constitute a way to store and transport liquid chlorine safely and efficiently. But for small plants it is not practical to use chlorine cylinder for immersion bath chlorination, so use of sodium hypochlorite is more common although the gas itself is cheaper.

In modern times various other additives to the immersion bath have come into use. Chlorine dioxide, acidified sodium chlorite and other have been reported²⁵. A detailed coverage is available in Chapter 6. The preferred level of chlorine dosing in the chiller bath is 15-20 ppm free, **bio-available** chlorine. USDA allows 20 to 50 ppm chlorine in the chiller water.

A hypochlorite is an unstable compound which breaks down and loses its chlorine content over time by decomposition, a process which is accelerated by heat, sunlight, and exposure to air and certain metals. Liquid sodium hypochlorite degrades into sodium chloride and oxygen, while calcium hypochlorite ends as chlorite and chlorate ions. To reduce decomposition they should be stored in cool, dark, and well-ventilated areas in smaller, tightly closed glass containers.

To ensure that the chlorine content in immersion chill water is maintained at the right ionic concentration it is necessary to **titrate** the master solution containing sodium hypochlorite. Titration must be performed every day, because, as stated here, decomposition reduces available chlorine over time. A further complication arises from the fact that the bio-availability of chlorine ions in the bath also depends on the concentration of cellular debris in it. Chlorine binds with cellular debris and correspondingly less chlorine ions remain available to deactivate pathogens. This aspect has been covered in the section on red water chillers.

Dosing of the master solution into the bath is done with the help of a volumetric dosing device such as Dosatron[®]. However, since it is designed for dosing medicines in drinking water line in poultry sheds, this device is not directly compatible with large water flow rates required in screw chillers. To overcome this problem, it is necessary to split the chilled water intake pipe into two branches before re-joining them and then lead that re-joined end into the chiller bath. One of the split branch pipes can have a smaller diameter, consistent with Dosatron[®] specifications. Master chlorine solution may then be administered through this branch. The other branch diameter may be made as large as required.

You will then need to place a multi-turn regulation valve upstream of (before) the split, so that you can accurately control flow rates simultaneously in both branches to achieve a 2.5 litres of flow of chilling water per kilogram of carcass throughput. Your valve must be followed by a flow-meter. Your flow meter reading will then show the rate of water flowing into the chiller bath, Dosatron[®] setting will show the dosing rate and the ratio of cross sections of the split pipes will give you the dilution factor. To cross check your calculations, and to make corrections for flow dynamics, carry out some actual titration tests for dosed chlorine in the chiller bath (dilution by melting of flake ice being taken into account), with various flow rate settings of the valve, and prepare a look-up table which your operator may consult every time he sets the chlorine flow rate on the Dosatron[®].

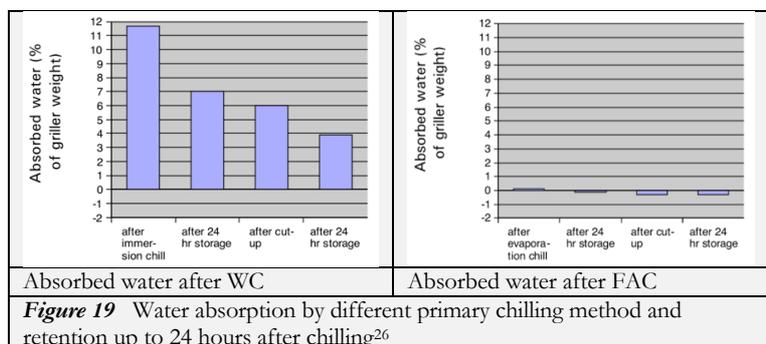


Figure 19 Water absorption by different primary chilling method and retention up to 24 hours after chilling²⁶



6 Water Pick-up & Thaw Loss In Immersion Chilling

The USDA does not specify dwell time for poultry carcasses in water baths. However, the FSIS specifies²⁷ that raw poultry carcasses and parts will not be permitted to retain water resulting from post-evisceration processing unless the processor demonstrates to FSIS, that any water retained in the carcasses and parts is an inevitable consequence of the process used to meet applicable food safety requirements. In addition, the processor will also disclose on the pack label the maximum percentage of water retained.

The quantity of water a carcass picks up varies – being mainly dependent on (1) dwell duration in the bath, (2) bird density within it for that duration, (3) carcass size, (4) efficiency of air injection into the bath, (5) chiller configuration – whether it consists of a single bath or a dual bath arrangement (refer Section 5.3 for an explanation), (6) temperature of bath and carcass and (7) damage, if any, on the carcass. Dwell time may be as high as 60 minutes or more, depending on the chilling technology used, consistent with the goal of reducing the core temperature to as close to 4°C as possible.

Water pick-up raises additional problems. Namely (1) the **quantity** that can be allowed to be picked up and retained, (2) the **quality** of water that is picked up²⁸ and (3) the **quantity** that may be lost as drip loss before it reaches the customer. This raises the question which consumers often ask - is water an adulterant in meat?

Region	Specs
Brazil	A maximum of 8% during carcass cooling
Canada (CFIA)	Processors to implement a validated program to control added water. Water-chilled carcasses*: 6%* Air-chilled carcasses 0.0% Carcass parts (chilled separately, salvaged, giblets) 8%@ *carcasses weighing 2.3 kg and over. @ provided a control program is in place.
EU	Specifies limits based on chilling method. Air chilling 2% Air spray chilling 4% Immersion (water) chilling 6% Exceeding 5%, additional labelling reqd.
USA (FSIS)	Allows inevitable pick-up due to process requirements and mandates declaration of pick-up percentage on the label
Maximum Pick-up Possible By suitable manipulation of carcass density in the tank and use of 2 tank method it is technically possible to reach 12%	
<i>Table 20</i> Permitted picked-up water limits in different regions	

Major differences in water pick-up according to the chilling system is shown in figure 19. These are from research done in 2004 at Russel Research Centre, Athens. Clearly immersion chilling allows pick-up of a lot of water. It equally allows rapid loss by dripping. FSIS estimates that the average retained water for chicken, as a percentage of net weight is currently in the 5.0 to 6.5 percent range in the industry. In absolute terms lower percentage will be picked up by smaller carcasses than by large carcasses because they reach the desired chilling with shorter dwell times. So according to factor (1) they pick up a smaller percentage of their body weight.

Findings of Lorenzetti et al	Remarks
A positive correlation exists between high absorption and carcasses with carcass defects, dwell time in pre-chiller stage & in chillers with bubbled air at 0.5 bar.	Corroboration: Dwell time (Young and Smith, 2004), agitation of bath, dwell time (James et al, 2006), bath temperature, bath agitation (Carciofi & Laurindo, 2007)
Torn skin (it allows bubble formation) & dislocated leg favours absorption while Klassen et al (2009) cite large abdominal opening interferes with it.	Frequent adjustments and preventative maintenance of EV and plucking equipment are needed to optimize water pick-up.
Breast muscles initially contain little water, get rapidly filled to saturation superficially through sheer hydrostatic pressure, eventually resulting in slowing of absorption.	Eventually, as reported (Carciofi and Laurindo, 2007), this water diffuses into the muscle through internal migration.
Best absorption within acceptable limits are dwell time of 60 minutes (all chillers combined), aeration pressure of 0.5 bar, and abdominal openings up to a maximum of 2 cm.	These chosen parameters were found not to influence the protein, moisture/protein ratio, pH, or lipid content of the carcasses.
Given a total dwell time of 60 minutes spread over 3 chillers, 46% occurred in the first where the temperature of carcasses and water were highest, 36% in the next and 18% in the last because by this time the tissue had already absorbed to near maximum capacity.	We can conclude that given undamaged carcasses, adequate air injection at 0.5 bar, and higher carcass and bath temperature contribute best water pick-up, a multi-stage chiller line up in which the first has a reasonable dwell time is best for pick-up.
<i>Table 21</i> Findings of the Lorenzetti et al study relating to water pick-up in immersion chilling. We have drawn our own conclusions where conclusions had not been presented in the study and recorded corroboration by others.	

A study on the role of factors influencing water pick-up in a three stage immersion chilling system was carried out by Lorenzetti et al²⁹ on 1,179 chickens at a large industrial processing facility in Brazil handling approximately 720,000 birds per day. Sampled carcasses had abdominal openings of up to 2 cm and experienced



a total dwell time of 60 minutes in a bubbled air stream compressed to 0.5 bar. Twelve variables were identified – (1) lineage, (2) sex, (3) carcass weight, (4) scalding temperature, (5) defect in carcass, (6) initial carcass temperature, (7, 8) water temperature in the two stage pre-chiller, (9,10) dwell time in the pre-chillers, (11) air injection in the chiller and (12) integrity of the chicken breast. The findings of this research have been tabulated in table 21.

The vital importance of water in meat has been covered in Chapter 6, Section 1.1 titled Edible Components of Slaughter. It shows that as much as 75% of the body weight is free water and this is what gives fresh meat its succulence. Besides, Sections 2 and 2.5 of the present Chapter tell you that pH and ionic charge of protein work to hold the free water in place, and if this balance is disturbed (by slow or improper freezing, for instance), proteins run the risk of getting denatured, thereby altering the organoleptic properties of meat. Finally some of the picked-up water is absorbed by meat after end of rigour mortis. Therefore, all-in-all it is important to encourage pick-up of water, but preferably limit it to between 5 and 6.5% as estimated by FSIS or to levels prescribed in your country. Beyond the levels presented in table 20, consumers would be right in considering the excess as an adulterant.

Given the clear finding by Lorenzetti et al that the maximum absorption occurs in the first chilling stage, we have yet another reason (besides 9CFR – see Section 5.7) to avoid cascading the discharge water from the last chiller to the first as a means to conserve chilling power and water consumption in the process because by doing so we unknowingly increase chances of contamination through picked-up water. Perhaps this is the reason why the FSIS formed the rule in the first place.

7 Sizing Your Immersion Chilling System

Technological factors aside, market conditions also impact your choice of the ideal chiller configuration. Later on, we will talk of market factors which impact your choice of not only the chilling method but also immersion chiller size. Now we consider the **intrinsic** factors that must govern your decisions.

7.1 Live Weight Versus Chiller Capacity

Briefly it can be said in our present context that all other conditions being constant, the rate of chilling is longer by far for larger carcasses than smaller ones and that the rate of chilling is rapid at first (since the difference between the carcass temperature and chilling medium temperature is large) and slows down progressively as the temperature difference between the carcass and the cooling medium reduces.

This is one of the reasons why international standards specify counter-current immersion chilling. But because of their obduracy or ignorance, all local fabricators fail to follow this simple and reasonable directive. We bring this problem up for detailed examination in Section 8 – Myths & Truths – Con-current of Counter-current arrangement?

To reach 4°C, it requires a much longer chilling time than, say, reaching 7°C for any given BPH figure. For example, it may take one-fifteenth of your chiller length for the carcasses to fall from 35°C to 32°C while it may take a quarter of the chiller length or more, to lower the same carcasses from 7°C to 4°C – even with flake ice being available in sufficient quantity.

7.2 Live Bird Price Versus Chiller Capacity

In any farm individual live-weights will follow the normal distribution curve at harvest time – only some of the birds will be of average weight while the rest will be either underweight or overweight, forming a bell shaped curve as figure 22 shows. Overweight carcasses take disproportionately longer to chill, so in effect the wider your bell curve, the less your average will dictate your required chiller length. So it is always best to specify the “average weight of carcass to be processed” at a higher value than the simple average. This honest subterfuge becomes more relevant when you aim to process birds aggregated from several farms on any given day. The

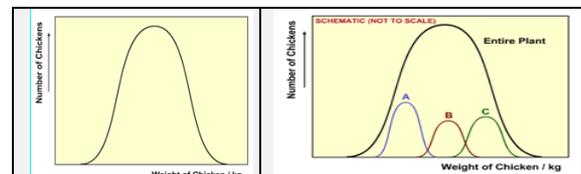


Figure 22 How the bell-shaped weight curve mandates that your chiller capacity must cater to larger birds and how aggregating live bird supplies from several farms worsens the situation when the peak of the curve representing each farm harvest will tend to widen and flatten your overall bell curve. These figures have been taken from The Big Cool Chicken³⁰



picture on the right side in figure 22 explains this phenomenon where the individual bell curves representing individual farms, taken collectively, widen the overall bell curve and place more birds in the overweight category.

When you specify the primary chilling needs for your processing plant, initial and target carcass temperatures must be mentioned in the enquiry you send to your vendor. You must also mention the desired product throughput per hour in your enquiry. So also must you mention the **average** and **maximum** carcass weight. When you do not clearly specify your target carcass weight and the target chilling temperature, vendors will fail to specify either the dwell time, or the carcass weight, or the target temperature in their offers. If you are ordering a two stage solution, be sure also to specify your desire to vary the dwell time in the first and second screw chillers **independently of each other** (see Section 5.5). Also take note of the discussion in Section 10.3 where **extrinsic** or market factors have been discussed.

8 Myths & Misunderstanding About Immersion Chilling

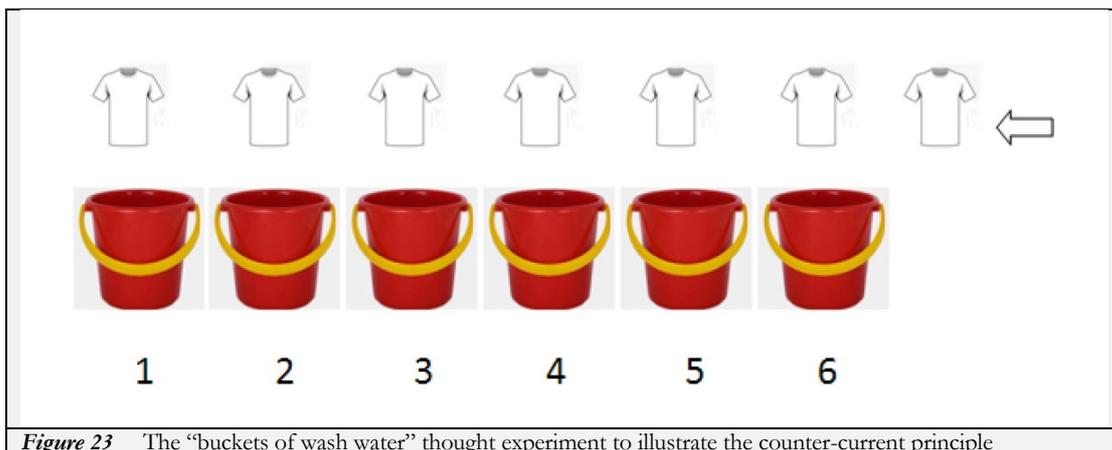
8.1 Myth One Con-current Or Counter-current Arrangement ?

All international standards that this author has come across mandate counter-current flow between water and carcasses in a screw chiller. Yet all screw chillers locally fabricated and sold in India and neighbouring countries for the past three decades are based on con-current flow³¹. Why is the con-current flow design principle completely wrong? Here is a convincing thought experiment.

Imagine that you have just soaped, soaked and scrubbed a large batch of soiled shirts and must now rinse them to get rid of the residual soap and dirt before you hang them up to dry. You have six buckets of clean water arranged in a row, and moving from right to left you must dip each shirt in turn into a bucket, rinse and squeeze it, before moving it into the next bucket to repeat the process. You start dipping in bucket 6 and end in bucket 1 and then onto the clothesline.

As you progress with your wash, soon the water in your buckets gets dirty. Now your friend fetches a seventh bucket containing clean water. Which of the six buckets should this seventh bucket replace?

The answer should be obvious. If you replace bucket 6, the next shirt will emerge from the cleanest possible wash and descend into the second dirtiest water in bucket 5! And so on. In the end the shirt will come out of bucket 1 which contains dirtier water than bucket 6! You will end up dirtying all your shirts – not cleaning them. Therefore the fresh water bucket must not occupy position 6, rather it should occupy position 1 and each of the remaining buckets (2 to 5) must move up one position. Then you must remove bucket 6, dump its dirty water and hand it, now emptied, to your friend to fetch more fresh water.



Now note the arrangement. **Shirts move from right to left** to get cleaned and **fresh water moves from left to right** to accomplish this cleaning process. We can conclude that shirt and water move in a **counter-current arrangement**. Likewise in a properly designed screw chiller **carcass and water must move in a counter-current arrangement** for the carcasses to get chilled.

Furthermore the counter-current flow is a fundamental principle which is used in any engineering step requiring 'exchange'. What do we mean by that? In our example soap and dirt are being exchanged between shirt and wash-



water. Likewise in a screw chiller heat is being exchanged between chicken and chilling water. Now let us imagine that we are extracting essential oils, flavour and aroma from herbs or extracting vegetable oil from crushed oilseeds in an industrial scenario. We exchange these molecules between herbs or oilseeds and a volatile solvent. We call this process solvent extraction. Here also a counter-current flow of solvent extracts these desirable components from a crushed mass of herbs and oilseeds moving in **opposite directions** in the extractor machine.

So far we have learnt that this principle is employed in the exchange of dirt, thermal energy and desirable molecules. But it does not end here - this principle is used in the design of annealing tunnels where metal or glass objects are required to be cooled at a **steady and carefully calibrated rate**. Conversely we use the reverse of the concurrent flow principle in the manufacture of automotive safety windscreen glass, where the outer layer of the windscreen is supposed to be frozen in a state of permanent stress. By freezing the stress forces, when the glass is impacted, it shatters into thousands of small pieces and cause minimum harm. Here a rapid and strong burst of refrigerated air is impinged onto the heated windscreen so as to create a permanent and uniform stress in its outer surfaces.

In the case of exchange of heat, difference in heat (ΔT) between the coolant and object needs to be constant and predictable. In the case of exchange of flavour compounds or vegetable oils, it could similarly be ΔF or ΔV where F and V represent concentration of flavouring compound or vegetable oil respectively, and so on, for other active components being exchanged. None of these exchanges could be achieved efficiently without using the counter-current flow principle.

8.2 Myth Two - Air Agitation In Screw Chiller Heats The Water!

To keep the carcasses fully immersed in the medium and thus to ensure best heat exchange (therefore best chilling speed) it is necessary to inject air into the medium. For this purpose one or more air compressors are provided with the chiller. They inject compressed air all along the medium.

Some plant managers object to this practice on the plea that compression causes the air to heat up and this heat is added to the bath, raising its temperature. Therefore they maintain that it is better to disconnect the compressor and inject no air at all!

But in fact injecting air into the bath is essential to get good chilling results. And the small amount of heat transfer from compressed air to chilling medium that this entails heats the medium ever so little that it is well worth the effort. Moreover, it is possible to lose a bit of this heat by using long compressed air header pipes, essential if you install air compressors outside the chiller hall, resulting in other windfall benefits, as recommended in Chapter 4.

This Author encountered one such obdurate plant manager several years ago in Pakistan, who insisted that heating of the medium by compressed air nullified all the benefits of having a screw chiller altogether. To evaluate this claim, Dr Shashidhar Ramachandra³² has calculated the heat transfer for Aptec, using two independent methodological approaches— sensible heat transfer calculation and compressor power consumption analysis. His analysis has demonstrated that the maximum theoretical temperature rise is less than 0.7° per chiller under extreme assumptions, and realistically below 0.3° per chiller. These values represent less than 0.4% of the total cooling load, which is negligible compared to the substantial benefits of air agitation. To conclude, air agitation (1) prevents thermal stratification, (2) disrupts insulating boundary layers and (3) ensures proper immersion of carcasses. All these functions improve yield. The original paper from Dr Ramachandra is available and a copy will be mailed to any reader who asks for it.

8.3 Myth Three – Cross-contamination In Screw Chillers Affects Shelf-life

Many poultry processing pundits³³ claim that a screw chiller causes cross-contamination because it places many carcasses into the same bath.

This argument hinges on these assumptions:

- (a) that birds within a flock inherently display vast variance in microbial load, in spite of having been reared in the same farm shed, transported together in tightly stuffed coops, hung and carried within 6 inches of each other on the killing and evisceration lines, dipped in the scalding bath together with others. They continue to



retain that variance in microbial endowment! Yet this variance in microbial load could not possibly have been because of chance spillage of gut microbes into the body cavity by improper evisceration.

- (b) it then follows that the variance in microbial load should continue after air chilling to result in carcasses of vastly different shelf lives: high in carcasses that started with low loads and low in carcasses that started with high loads. And therefore in water chilling there is an across-the-board reduction in shelf life of **all** carcasses by averaging out of microbial load.
- (c) that reduction of A_w in air chilling has nothing to do with increase in shelf life.
- (d) that reduction of competition from species other than *Campylobacter* (the principal spoilage organism) in air chilling plays no role in enhancing shelf life.

In subsequent sections we have reported quality aspects by method of chilling and have entirely failed to observe large variations in microbial load among air chilled carcasses. In fact we have recorded several instances where researchers found microbial loads on water chilled carcasses to outperform air chilled carcasses! How can we explain this? Let us begin by examining the circumstances under which this pseudo-scientific cross-contamination hypothesis originated.

Around the end of the last century two trends in industrial processing of poultry came into vogue almost at the same time - automatic evisceration and air chilling. The latter was an attempt to improve the shelf life of processed poultry while the former was to reduce processing cost. Air-chilling was part of a general move towards improving GMP. Now imagine someone carries out research on the microbiological effects of immersion versus air chilling at this time. The less progressive and older plants would be using WC, semi-automatic or manual evisceration, in which spilling of gut contents into the abdominal cavity was common and pursuing poor GMP. At the same time more progressive and newer facilities would be doing the exact opposite - more so if the experiments were carried out in Europe, which they were. There was bound to be a sampling bias.

Results of research on comparative advantages of air and water chilling have been tabulated in Section 10.5. Table 28 shows the microbial loads for immersion and air chilled poultry. There is no significant difference in initial microbial load and very little spread of data. Table 29 shows that AC resulted in a more diverse microbiome that may delay the dominance of the principal spoilage organism *Pseudomonas*.

Therefore the only way we can reconcile the research findings in Section 10.5 and this popular misconception is by accepting that this hypothesis originated from a sampling bias. To conclude, improvement of shelf life is due to (a) reduced water activity (A_w) in air chilling, (b) diverse microbiome and consequent competition to *Pseudomonas*, (c) dilution effect in immersion chilling, (d) germicidal effect of chlorine wash in immersion chilling and (e) improved modern evisceration techniques in which gut content spillage is no longer common.

And while we are so preoccupied with microbes on the surface of broiler meat, we may also like to note the role of airborne microflora in process areas, particularly in the context of air-flow design within poultry slaughterhouses.³⁴ For more on this subject read Chapter 4.

8.4 Myth Four – Position Of Water Discharge Spout Does Not Matter

Despite rapid developments in screw chiller design, some local fabricators have combined the worst features of the paddle design in their current screw chiller offerings. The illustration in figure 24 shows that the water discharge point is directly below the cold water inlet. This makes it a static bath in which the screw functions like a futile paddle with an ‘attitude’ – always shoving carcasses in one direction, regardless of the direction of flow of water.



Figure 24 In this local model the screw and its drive (middle view) are completely superfluous – the machine is designed to masquerade like a screw chiller and function like a static tank. Note the picture on the right shows the carcass discharge at the top and water outlet at the bottom – exhibiting a complete departure from the counter-current principle.



8.5 Myth Five – Immersion Chilling Uses Water While Air-Chilling Does Not

Approximately 2.5 litres of water is prescribed per kilogram of carcass weight in immersion chilling, whereas in air chilling there is no prescribed usage of water. However, carcasses entering the air-chill tunnel are made to pass through a fog of water. Fog particles that settle on the carcass instantly freeze upon contact with cold air in the tunnel and form a thin glaze which prevents desiccation. Assuming that fogging results in the usage of say, 100ml of water per carcass (weight of the carcass being inconsequential here), we need to compare this with water consumed in immersion chilling. The ratio would be 2500/100 or 2.5%, signifying that air-chilling uses only 2.5% of the water that immersion chilling does. But we would be wrong in drawing that conclusion. This is why:

Assume that we have two 6000 BPH plants, each operating 10 hours per day and each producing 1800 gram carcasses. One of them uses air-chilling while the other uses immersion chilling. For our calculation in table 25 we have assumed that the immersion chilling plant uses a 15000mm screw chiller of 2100mm diameter. In this

plant the chiller is filled at the commencement of the shift and the water is replenished continuously. At the end of the day the bath is emptied. From the calculations in table 25 it is evident that smaller plants save more water per bird with air-chilling and the heavier your bird, the more water you save with air chilling.

Plant	Calculations	
Immersion chilling plant	Direct consumption of water/day in litres is : $W \times R \times P \times b / 1000$ $1.7 \times 2.5 \times 6000 \times 10 = 255,000$ litres	(1)
	Fill capacity of screw chiller in litres is: $9970 \times N / 6$ $9970 \times 15 / 6 = 24,925$ litres	(2)
	[Where W = eviscerated weight of carcass in kg; R = recommended wash/kg in litres; P = plant capacity in carcasses per hour; b = hours of operation per day; C = consumption of water per day; 9770 is obtained from line 4.5 in endnote 32]	
	Specific consumption/carcass in litres is : $C / (P \times b)$ $(1) + (2) / (P \times b)^*$	
Air-chilling plant	Consumption of water/day in kilolitres: $60000 \times 0.1 = 6$ kilolitres	
	Specific consumption of water per bird is 0.1 litre	
Table 25 Water consumption compared.		
* Chiller is filled every shift and the water is discarded at the end of that shift.		

8.6 Myth Six - You Can Recycle Water In Immersion Chilling

Although there is much concern about conservation of water in poultry processing through recycling, at the present state of technology we feel it is both unwise and infeasible to recycle most of this water. For a complete understanding of this subject, and for exploring ways and means of reducing consumption of water in general, please refer to the article “Water Recycling in Poultry Processing - State-of-The-Art Today” on www.aptec.in. Meanwhile, we note two common instances of water reuse - one of which is an acceptable practice.

- Offal slurry which includes feathers and heads (but not blood), is commonly moved as slurry for rendering after filtration. The filtrate is frequently brought back into the processing plant and used for assisting the flow of feathers in the floor-gutter and for initial soaking of live bird coops. This practice has been covered in detail in Chapter 13, complete with flow diagram.
- In some plants where a two bath immersion chilling system is in use, discharge from the second (2°C water bath) is pumped into the first bath. This goes against the 9CFR rule as explained in Section 5.7.

9 Plain, Fogged & Evaporative Air Chilling

International standards require 2.5 litres of wash/chill water per kilogram³⁵ of carcass being chilled by the immersion chilling process. All air chill methods (AC, FAC and EAC) save water and this is the main reason favouring their increasing popularity. Important features of air chilling are:

- By air chilling you save water.
- Water chilling allows water pickup while air chilling causes desiccation – these, taken together result in large yield difference between these chilling methods.
- Air chilling permits traceability while immersion chilling hinders it.
- There is a big difference in capital cost and operating cost between these processes.



- Water chilling is blamed (erroneously) for causing cross-contamination and consequently reducing shelf-life.

Plain air chilling (AC) subjects a carcass to a blast of air at between -1 and 0°C in a tunnel for 90–150 minutes in order to rapidly cool, but not freeze it. In the process the carcass loses moisture. To reduce moisture loss, in a variant of AC, a carcass is subjected to a fog of water before it encounters the desiccating blast of cold air. Encountering cold air, dew on the carcass turns to a thin film of ice which prevents desiccation. We will call this method fogged chilling (FAC). Finally, by combining WC and FAC and playing with the variables, we come up with evaporative air chilling (EAC). Several variations of EAC were tried by the industry and continue to be tried. These trials have established certain features which we will discuss here.

Should the process of fogging in FAC be taken beyond a point, water on the surface of a carcass will no longer immediately form a protective ice film, but will slowly evaporate and start forming ice, wherever it can within the confines of the tunnel. Several things will happen simultaneously and all of them will be because we have tampered with water usage in the system:

- Excess **water** will raise the tunnel RH (relative humidity) and clog evaporator coils.
- By evaporating from the surface of the carcass **water** will accelerate carcass chilling.
- In forming ice, **water** will compete with carcasses for system TR (refrigeration capacity). And in response the technician will increase the operating parameters of the system.
- **Ice** on overhead carcass conveyor will make it malfunction or fail.
- With added **ice-making load** and clogged evaporators, the refrigeration system will struggle or fail altogether.

All these symptoms were experienced at a new plant in India around 2014 when its managers, who had installed air chilling despite this Author’s counsel, desperately tried to modify the fogging system into a sprinkling system when his customers refused to buy air chilled chicken ^{36!}

To prevent the formation of ice in FAC, air temperature is kept just above the freezing point. To employ the EAC principles, instead of fogging carcasses, they are subjected to either sprays of water several times while they are chilled or are dipped several times in water as they are transported on an overhead conveyor. EAC takes advantage of both traditional chilling methods³⁷. It can improve heat transfer, minimize mass loss and reduce skin discoloration when compared with air chilling³⁸ and has been reported to cause minimal water absorption (±1% of initial carcass mass), depending on the frequency of water spraying/dipping and on the cold air conditions³⁹. Comparing all three methods of carcass chilling, scientists have arrived at favourable findings in product quality, weight gain, chilling time, yield and shelf life of poultry meats in favour of EAC⁴⁰.

Comparison of Operating Cost – Air Vs Immersion Chilling			
Input Design Data		Airchill	Waterchill
Capacity	BPH	2000	
Production shift	Hours	8	
Number of production days/year	Nos	300	
Maintenance cost as % of capital cost	%	2	
Maximum eviscerated weight	Kg	1.65	
Product out temperature	Deg C	4	
Conversion rate (INR in a Euro)	INR	85	
Depreciation rate (capital investment)		10	
Input unit cost data in INR			
Raw water (One INR per kilolitre)	Kl	50	
Power (kWh cost in INR)	kWh	8	
Labour (per person per day in INR)	Per day		
Building space capital cost/SqM	INR		
Derived building space cost per CuM	INR		
Input capital cost in INR millions			
Total delivered and installed cost comprising O/H conveyor, rehangng belt, screw chillers 1x2.1x3m+ 1x2.1x6m; customs duty; steel superstructure; refrigerated water chillers; ammonia coolers; pipework; water recirculation pumps; flake ice makers; compressor building	INR millions	51.91	16.51
Table 26 Capital cost and operating cost comparison for chilling arrangements in a 2000 BPH plant in India showing FAC versus water chilling options. This customizable spreadsheet can be e-mailed upon request			

10 Chilling Methods Compared

10.1 Cost Comparison

The calculations shown in figure 26 are a facsimile of an interactive spreadsheet prepared by the author in 2014. An updated version may be obtained as an App from Aptec on request. The user may plug in his own capital cost data and obtain a comparison in operating cost between WC and FAC. Comparison with EAC will also be possible in a future revised version.



10.2 Efficiency Comparison

Readers who are interested in the heat transfer rate by the two competing methods of chilling poultry may refer the report by Landfeld and Houska (2006)⁴¹. These scientists used a metallic chicken (cast of tin-lead alloy in a plaster mould, with size and shape corresponding to a chicken carcass weighing about 1.5kg) as a simplified physical model for estimating the convective heat coefficient in an air blast chilling tunnel and verified the influence of evaporative chilling on this parameter. They reported values of convective heat transfer coefficient of approximately 50 W/m²/K between the sample and the chilling medium and for evaporative heat coefficient, a value of 19 W/m²/K for 0.42 mass transfer factor.

Mielnik et al (1999) and James et al (2006) have reported, based on both temperature differences and known carcass weights, that carcasses subjected to a 50-min EAC lost 1.8 kcal/kg more than carcasses subjected to FAC during the same time period.

10.3 Traceability

Since the carcasses are dropped into a screw chiller before they are again hung onto the sorting line overhead conveyor, traceability down to the cut or carcass level is not possible with water-chilling. Traceability down to specific cut or carcass requires that carcasses remain on the overhead conveyor line from the time they are hung as live birds to the time the edible product gets packaged and bar-coded to eventually reach the consumer. At present one can only narrow traceability down to flock level provided the process plant allows some gap between batches entering and exiting the screw chiller. But this is difficult to put into practice. Therefore should traceability become mandated by law, as a technology, screw chilling may become extinct unless a carcass-bar-coding-on-line technology, under development now, reaches marketable status by the time such a mandate comes into force.

It should be borne in mind, however, that in small plants which do not install automatic re-hanging systems (automatically transferring carcasses from the killing line to evisceration line to air chilling to weighing-grading to cut-up lines, etc), traceability is not possible anyway. By small plants we refer to those which are designed for below 6000 BPH. Since most plants in South Asia fall in this category, the traceability debate actually becomes one about capacity and capital cost rather than about method of chilling. So if traceability has to be implemented strictly, most of the small and tiny plants may also have to be phased out by law.

10.4 Market Factors

Earlier we have referred to market and environmental conditions as **extrinsic** factors that affect your plant design. One important extrinsic factor is broiler price volatility, because of which processors must necessarily have the facilities to freeze and stock. Any policy relying on producing only fresh chilled poultry is bound to fail and therefore your plant must have a judicious mix of capacity to produce both fresh chilled and frozen products. One Indian company in particular chose to ignore this rule and built two facilities completely lacking any freezing facility altogether, around a quarter century back. That company is now on the verge of exiting the poultry processing business altogether.

If you are venturing into this business, study the market demand in your area and decide on a suitable capacity for freezing and storing frozen poultry at your plant. Extrinsic factors that affect your carcass chilling and freezing system design are:

- Large price volatility in the live bird market
- Variations in poultry consumption over the year (figure 27)
- Seasonal variations in farm output
- Competition from the wet market
- Near absence of import and export of processed poultry
- Conservative customers

10.4.1 Price Volatility

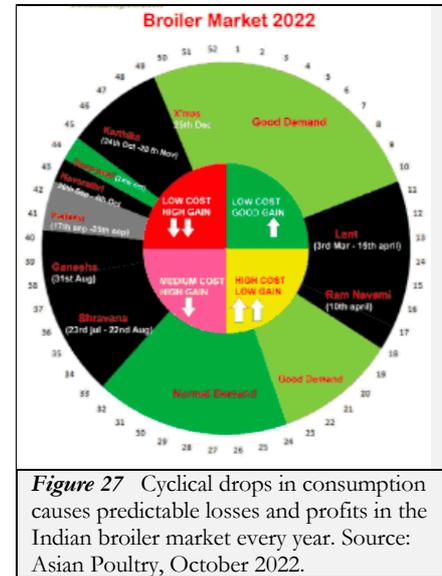
There are only two supply lines of commercial broiler DOCs in India and since there is virtually no foreign trade in broilers, breeders, DOC etc, there is intense competition between them. This competition includes periodic



engineered short-supply or over-supply of broiler breeders and consequently production of broiler DOCs. This causes price volatility, shortages and gluts. Engineered price volatility is worsened by poor and uncertain summer harvest of broilers owing to the predominance of open shed farming (by our study only 15-20% of commercial farms are EC – the rest being open sheds, often lacking even a proper masonry floor).

On a large number of days every year parts of the population turns to a vegetarian diet for religious reasons. An article in Asian Poultry in the October 2022⁴² issue highlighted this fact (figure 27). This further affects demand for poultry. Because there is virtually no mechanism to buffer the difference between production of live birds and market demand, processing poultry does not always turn a profit (although over the year, the industry does make good profits), because processors have the means to freeze and stock frozen poultry. How does this affect the live bird size arriving in your plant?

At the beginning of a glut, a farmer delays harvest of his flock, hoping for a rise in prices. Consequently his flock gets heavier and heavier, till at the time of harvest all his birds become decidedly heavier than normal. So during a price glut, not only must you run your plant at higher BPH speeds, for longer hours, but also with heavier birds (to maximise your profit). For this reason you need to design your plant with **stamina** to (1) take in more operating hours, (2) at higher line speeds and (3) with heavier birds, all of which accompany a glut. We have now covered all ways and means by which you can design your chilling and freezing capacities to take advantage of price gluts.



10.4.2 Salmonella

Because of the prevalence of open shed farming there is a strong presence of salmonella in live broilers. With water chilling it is possible to control salmonella and other microbes by the addition of chlorine in the bath. We believe that farming practices may take several years to improve. That is why if you are fundamentally in favour of air chilled poultry we recommended water chilling in the beginning, followed, if you wish, by your preferred form of air chilling.

10.4.3 Conservative Customers

The Indian customer is suspicious of the dry appearance of air chilled poultry. Dryness is considered by the Indian customer an indicator of an old product, and therefore undesirable. The Indian market is very conservative and it is not easy to convince them otherwise. Remember even today the Indian consumer prefers deskinning carcasses because he is familiar with the age-old wet market practice of deskinning as a method of defeathering. So he continues to think skin-off carcass is a quality attribute.

As mentioned elsewhere, this was the alarming observation of the single company that insisted on air chilling on the strength of its international experience. Because of this, complete replacement of water chilling by air chilling is unwise, although a short period of air chilling following immersion chilling is likely to be the best compromise because it will rid the carcass of salmonella and appreciably reduce water activity.

10.5 Quality Factors

We have assembled here nine research findings spread over 1979 to 2022 seeking to bring out the quality differences between various carcass chilling methods.

10.5.1 Belk et al⁴³

This study was conducted at the University of California, Davis (UC Davis) Meat Science Laboratory using AC and WC methods of chilling carcasses. The main findings were:

- (a) AC resulted in superior chicken odour and shelf life.



- (b) AC poultry microbiome was more diverse – a fact that may reduce the dominance of the principal spoilage organism *Pseudomonas*.
- (c) Potential economic advantages to AC where water costs are more significant than energy costs.

Colour, Organoleptic Properties & Texture.

Assessment showed that values were greater for AC breasts than WC breasts throughout the display period, indicative of more desirable red and yellow tones within the muscle of AC breasts. Boneless chicken breasts were more desirable than bone-in breasts during the 3-day display period following 7 days of dark storage. Although there were notable differences in instrument colour readings between the chilling methods, the difference was not observed in consumer preference.

Chilling method, organism type, product type	Day 1	Day 7	Day 14
Water chilling, psychrotropic	1.05 log CFU/g	6.59 log CFU/g in chicken breasts	All products, bone-in or boneless, either chilling method, had mesophilic organisms > 7 log CFU/g, (commonly associated with the end of shelf-life).
Air chilling, psychrotropic	2.12 log CFU/g	5.56 log CFU/g in chicken breasts	
Mesophilic WC/AC	No difference		
Bone-in versus boneless	Regardless of chilling method boneless had fewer microbial counts than bone-in		

Table 29 Psychrotropic & mesophilic microbial counts in air and water chilled bone-in and boneless products over a time period. In general the study demonstrated that AC resulted in a more diverse microbiome that may delay the dominance of the spoilage organism *Pseudomonas*. From Belk et al.

During the 3-day display following 14 days of dark storage, panellists considered the colour and odour of all samples unacceptable regardless of the chilling method or fabrication (portioning or deboning) type. Chilling method and fabrication type did not have an impact on texture. Additionally, trained sensory panellists detected no differences in flavour or texture attributes between the chilling methods.

Lipid Oxidation.

Lipid oxidation increased as the time after chilling progressed and was similar across chilling methods and fabrication type on the initial day of processing, 7 and 14 days of dark storage, and 7 days of dark storage with 3 days of retail display. The greatest differences between treatments were seen on the samples collected after 14 days of dark storage and a 3-day retail display.

Nutritional & Dry Matter Content.

Nutritional content was very similar between chicken breasts regardless of chilling method. Dry matter measurements ranged from 26.7% to 28.3%, with an overall mean of 26.13%. Within this narrow range, the only difference between treatment groups was between bone-in and boneless breasts collected on the initial day of experimentation. Chilling method, dark storage, and retail display did not impact dry matter content of the chicken breasts. The same pattern was detected in moisture.

Product Biochemistry.

Measurements of ash and crude protein revealed a few differences between treatment groups, but these did not reveal significant patterns. Crude fat values were, overall, low for all chicken products, ranging from 0.35% to 1.43% with a mean of 0.86%. Carcass samples and bone-in breasts had higher crude fat content within almost all chilling methods.

Following this trend, the relative abundance of fatty acids was not grossly different between chilling methods. However, among fatty acids with less than 10% relative abundance, linoleate methyl ester was more abundant in WC than AC breasts after 7 days of dark storage with 3 days of retail display.

Time	Psychrotrophic Bacterial Count (log CFU/g)			
	Bone-in		Boneless	
	Air chilled	Water chilled	Air chilled	Water chilled
Pre-fabrication	2.12	1.05	2.12	1.05
Post-fabrication	1.90	1.81	0.61	0.68
7-day storage (day 7)	5.86	6.96	5.26	6.22
End of display (day 10)	7.00	6.92	6.44	6.42
14-day storage (day 14)	8.71	9.00	8.51	8.67
End of display (day17)	9.11	9.41	8.63	9.24

Table 28 Psychrotrophic bacterial counts for bone-in & boneless chicken breast cooled by either air chilling or water chilling pre- & post-fabrication, pre- and post-chilling, during storage and during and after display. The standard deviation for all values in this table ranges between 0.15 & 0.16, with *P* < 0.05 (refer original article for details). From Belk et al.



10.5.2 Berrang et al⁴⁴ - Effect Of Chilling Methods On Microbial Flora

This study, conducted at the Agricultural Research Service - Russell Research Centre, Athens, USA, compared the effect of two chill methods on broiler carcass bacteria. The data showed that immersion-chilled carcasses had a lower numbers of bacteria, although the small difference may be attributed to simple dilution. Both chilling methods were effective in lowering carcass temperature, and neither chilling method seemed to select for specific species, subtypes, or antimicrobial-resistant *Campylobacter*.

Although significantly fewer of each bacterial type were detected per millilitre from WC carcasses than from AC carcasses, in each case the difference was less than 1 log₁₀ cfu/mL (Colony Forming Units per millilitre). Chilling method did not affect species; both *Campylobacter jejuni* and *Campylobacter coli* were recovered.

Chill treatment	Total aerobic bacteria	Coliforms	<i>E. coli</i>	<i>Campylobacter</i>
Air chill	3.83 ± 0.10	2.53 ± 0.13	2.42 ± 0.13	2.40 ± 0.27
Immersion chill	3.40 ± 0.11	2.05 ± 0.10	1.86 ± 0.12	1.81 ± 0.27

Table 30 Mean log cfu (±95% confidence interval) aerobic bacteria, coliforms, *E. coli* & *Campylobacter*/ml of rinse of carcasses chilled in air or immersion. From Berrang et al

10.5.3 Carroll et al⁴⁵ - Shelf Life and Quality of Marinated Broiler Breast Fillets

This study was conducted at Texas Tech University Meat Lab, using 160 carcasses in each chilling method. Marination of broiler breast meat has become an integral part of the poultry industry due to the increase in consumer and retailer demand for further processed, ready-to-eat foods. Marination quality parameters in broiler meat may be affected by the chilling system as these influence moisture uptake. Table 31 shows the results.

	Quality Aspects	Remarks
1	Impact on shear force	AC fillets were more tender and had lower shear strength. However, these shear force values are well within the acceptable ranges for consumers (Cavitt et al, 2004a).
2	Impact on L	The air-chilled fillets had a lower L ¹ value. (L stands for a measure of lightness). A lower pH is associated with denatured sarcoplasmic proteins, which cause scattering of light and therefore make the meat appear lighter, as indicated by a higher L value (Swatland, 1993).
3	Impact on pH	
4	AC increases marinade pickup & retention in breast fillets	Probably due to residual moisture loss in AC and remaining cause for water uptake even at this stage of the experiment.
5	Both processes had similar cook loss	Moisture pick-up from marinade in AC samples compensated for water pick-up during WC
6	Impact on shelf life with lower aerobic plate counts	The research cites higher risk of cross-contamination being greater with WC. However this is an old hypothesis, repeated <i>ad nauseum</i> in the literature and has been ruled out in Section 8.3 of this Chapter
7	Sensory evaluation	19% indicated differences in texture and 9.67% indicated differences in flavour. Texture differences could be due to the differences noted in WC (WC had higher cooked moisture) and the shear force (WC had high shear force).

Table 31 Summary of quality aspects compared in the Carroll et al study

10.5.4 Compilation of Findings – The Poultry Site⁴⁶

This study records that in 2008 seven US plants had already changed over to some form of air chilling for which they charged a premium, while the remaining used immersion chilling. A transition was taking place in the face of water shortage and more and more plants were adopting FAC and EAC. However, this article mentions one of the biggest concerns for both FAC and EAC – namely that of cleaning and sanitizing the

Features	WC	FAC	WAC
Scalding	Hard, 56.7°C, 120 s	Soft, at 50°C for 220 seconds	
Air velocity, temperature	Not applicable		1.0m/s at 0°C
Ice slurry temperature	0.2°C	Not applicable	
Spraying	Not applicable		5 min int.&
Stirring	Air blown at 0.5 bar	Not applicable	
Temperature reduction in	55 minutes	155 minutes	120 minutes
Moisture pick-up/loss	4.6%	- 1.5%	1.0%
Moist loss (cutting after 5 hrs	2.5%	0.3%	0.4%
Moisture loss after 24 hours of storage	Lost almost 83% absorbed water	Maintained weights close to the prechilled weights.	
Instrumental colour evaluation	Less discoloured	Darker & yellowish	Less discoloured

Table 32 Results of study carried out by Jeong et al. AC requires a soft scald to prevent skin discoloration caused by the loss of the epidermis during plucking, whereas colour of WC carcasses is retained with hard scald. The report notes Veerkamp, (1985) said EAC was designed for hard scald but suits soft scald carcasses.
 &0.4°C water spraying (0.5 L/carcass)



chilling areas. They noted that it was much easier to clean and sanitize an immersion-chilling area.

The researchers found no difference in colour and texture of skinless breast fillets from carcasses treated with WC and EAC methods. WC poultry fillets showed slightly lower cooking yield, which the researchers attributed to the loss, upon cooking, of picked-up water. Testing breast fillets which had been prepared after a 150 minute maturation period, the researchers found that some 70% WC fillets were either slightly-tough or tough, while only 44% EAC fillets were slightly-tough or tough.

10.5.5 Huezo - Microbiological Impact on Chilling Method⁴⁷

Three studies were conducted using WC and EAC to find their impact on bacterial recovery, carcass quality, meat functionality and meat quality. Results showed that in the absence of intervention by any germicide both air and immersion chilling show microbiological equivalence. Bacterial reductions of up to 1 log units were obtained for *E. coli*, coliforms, and *Campylobacter* using either EAC or WC. In terms of appearance, pH, colour and texture of broiler breast fillets also there was no noticeable difference for air and immersion chilled carcasses. However, chilling method did affect carcass skin appearance and yield. Fillet functionality was improved by air chilling resulting in higher cook yield.

10.5.6 Jeong et al.⁴⁸

This study was conducted to investigate the effects of WC, FAC, and EAC on the moisture content,

Chilling Method	Chilling Yield (%) ^a	Fabrication yield (%) ^b	Drip loss in each part upon portioning (%) ^c					
			Breast	Wing	Thighs	Drums	Back	Average
WC	104.6	102.1	1.5	1.1	1.3	0.7	1.4	1.3
FAC	98.5	98.2	0.8	0.4	0.2	0.2	0.3	0.5
WAC	101.0	100.5	0.8	0.5	0.2	0.3	0.4	0.5

Table 33 Chilling & portioning yield (after 24-hr). Std dev figures were omitted. Study by Jeong et al.
^a measurements were made immediately after chilling;
^b measurements were made after portioning following a 5 hour postmortem period;
^c measurements were made after overnight storage.

processing yield, surface colour, and visual appearance of broiler carcasses.

Besides the salient findings in table 33, Jeong et al reported that both chilling methods and scalding types could influence carcass skin colour (yellowness or whiteness), swelling, shrinkage, and the finished carcass weight. The study also presented portioning performance after a 24 hour period, which has been summarized in Table 33 while comparative chilling rates which were recorded during the study are shown in figure 7

Significantly, this reinforces the fact that freezing poultry slowly ruins it permanently. This is also what happens when you use an under-powered freezer or when you freeze and thaw poultry several times in undersized display cabinets. In the retail setup the latter happens when the shop owner repeatedly switches off the frozen poultry display cabinet when closing his store for the night.

Chilling Method	Breast (%)	Wings (%)	Thighs (%)	Drums (%)	Scapulae (%)
WC	75.7	76.1	76.0	77.06	76.5
FAC	75.5	76.1	76.2	77.3	75.9
EAC	75.7	75.5	76.0	77.0	75.1

Table 34 Moisture content after 24-h storage in 5 different parts of broiler carcasses by different chilling methods. Standard deviation figures have been omitted. Study by Jeong et al.

10.5.7 Pedersen, (1979)

Pedersen’s study concluded that in terms of impact on local costs, and considering energy only, WC was reported as five times cheaper than any form of AC. However, when water and wastewater disposal

Parameter	WC	EAC
Temperature at the end of chilling (breast muscle)	19.6°C reached in 1.8-2.5kg weight category	10.8°C reached in 1.8-2.5kg, 4°C wt. category; 4.9°C reached in <1.2 kg
Total viable count (TVC)	Decrease	Increase in all weight categories except <1.2 kg
Enterobacteriaceae (ENT)	Similar, (as reported by Caroll & Alvarado, 2008)	
Sensory flavour and texture	Similar, (as reported by Zhuang et al, 2009)	

Table 35 Results of study carried out by Popelka et al

costs were included, the water chilling system became more expensive than the air chilling system. Pedersen pegs this cost at 50 times more than WC, taking into account local laws, water cost and relative energy cost of effluent treatment with technology in use some 45 years ago in Denmark.



10.5.8 Popelka et al⁴⁹

The aim of this work was to compare two chilling methods, EAC and WC in terms of their effectiveness in chilling of different weight categories of broilers and to assess their impact on their microbiology. The establishment where this study was conducted, sold its products in Slovakia and the EU.

EAC was carried out at a temperature of -1 to +3 °C at a sprinkling pressure in the inlet jet of 0.2-0.4 MPa and 1 MPa at the outlet, for 90 minutes, regardless of carcass weight. WC was carried out in cold water (0-4 °C) for 20 minutes, with a water consumption of 1.5 litres/pc. TVC was determined for *Enterobacteriaceae* and *Salmonella*.

10.5.9 Rodrigues et al – Research With Sensor Implants in Carcasses.⁵⁰

The objective of this study, carried out in Brazil, was to evaluate the effect of poultry carcasses by chilling methods WC, AC and EAC (using periodic water immersion) on the chilling rates, water loss and heat/mass transfer between the carcasses and the chilling fluid. For this purpose a specially designed experimental apparatus was used. In the apparatus a carcass with temperature sensors implanted into its pectoral muscles was placed in a cold chamber with a data acquisition system for measuring air relative humidity and air & carcass temperature. For measuring carcass behaviour in immersion chilling, similarly, a system for driving, lifting and lowering carcasses (with similar sensor implants) into the water bath was set up.

Time-temperature dependence of poultry breast as the carcass chilled under different treatments enabled the researchers to measure the chilling trajectory based on air velocity and relative humidity. The results showed that it is possible to reduce water loss by approximately 50% and chilling time by between 14.5 and 1.5% of the FAC method using the EAC method.

11 Hybrid Chilling System - Best Configuration for India

Ridding carcasses of surface bacteria is of paramount importance in poultry grown in South Asia. This can be achieved by immersing carcasses for a sufficient length of time in water containing free chlorine. Washing in the inside-outside carcass washer does not give adequate contact time. On the other hand, producing carcasses with a long shelf-life is equally important, especially when there is increasing demand for fresh-chilled poultry.

Because commercial broiler farming is predominantly in open sheds today in India, where it is impossible to implement modern methods of bacterial control, you must chill poultry with a chlorine dosed immersion method to bring down bacterial load to manageable levels. Therefore, after initial chilling-cum-washing in chlorine-dosed water in a screw chiller in this manner for approximately 30-45 minutes, you may choose to reduce surface water to lower the water activity or A_w (refer Chapter 7, Section 3.3.1) in a bid to further improve product shelf life by air chilling for 10 minutes or more.

12 Blast Freezing

The cooling process does not end with bringing the temperature down, just short of freezing. For true long-term storage we must freeze poultry. As shown in figure 2, if you continue cooling poultry for a sufficiently long time, you will eventually freeze it. Earlier this is what used to happen. Processors cooled poultry slowly till it froze over and was then transferred it to the frozen store. But the practice changed with the patenting of blast freezing or flash freezing in 1949 in New Zealand.

Blast freezing exposes products to a high velocity stream (typically 5 metres per second or 18 kmph) of very cold air (between -35 and -40°C) in the poultry industry. Such a high velocity extracts heat rapidly from the product and causes it to freeze. The phase change occurs rapidly, the temperature of maximum activity is transited rapidly and so the product undergoes minimum damage.

Today, frozen poultry is held at -18 to -20°C in frozen stores and is said by ASHRAE (American Society of Heating, Refrigeration & Air-conditioning Engineers), to be good for consumption for up to a year. Although there is some deterioration of eating quality compared with fresh or chilled meat. Typically this relates to deterioration of fats and fat soluble vitamins⁵¹.

Blast freezing requires ammonia based refrigeration. CFC or HFC systems are generally inadequate for generating the very low temperatures required for the process. Also, in a typical poultry processing plant, it is



better to opt for a **central ammonia based refrigeration plant** with high and low stages, and designed in such a way that a properly chosen bank of compressors may serve the entire plant and yet retain spare compressors for both stages. To our knowledge only one major processing plant in India chose HFC based refrigeration system for their entire facility. Table 36 provides a template that may be used for designing the central refrigeration plant. Let the vendor divide column B into 48 columns, with each of them representing a half hour interval, starting from midnight and ending at 2330 hrs. Then fill in the corresponding values depending on scheduled running time of each machine.

For your refrigeration system vendor to know your standard daily schedule, you will have to read Chapter 3 of this Handbook and help him to prepare a schedule similar to the one shown there. It explains how, by **departing from the conventional notion of operating shifts**, you can improve your plant’s performance

When your refrigeration system vendor uses the template of table 36, he will be able to arrive at the total compression capacities for the two evaporating temperatures that he has chosen. He would then match these figures with those of available compressor models and determine the number of units that he needs. At this point he will add spare standby compressors for both high and low stages. For steady loads he may choose rotary compressors and for intermittent loads, peaking loads and standby, he may opt for reciprocating compressors. Any use of CFC or HFC may be restricted to frozen stores and Sunday storage loads, and kept out of the central design. A central refrigeration plant is vastly superior in terms of cost, performance and reliability that individual compressors dedicated to individual loads.

13 How To Design Your BF System

13.1 Rule 1 – A Suitable Combination of BF & FC Capacities

To our knowledge only one company venturing into poultry slaughter in India chose to restrict their plans to production of fresh chilled poultry on the strength of a market research that showed that the European market prefers fresh chilled poultry over frozen poultry. Because there are wide fluctuations in demand and production for poultry in India, it is always safe to build some capacity for freezing and storage of processed poultry. Such a capacity enables the processor to buffer his production and set up a mechanism for protecting the company’s bottom line.

13.2 Rule 2 – BF Schedule

If your plant begins slaughtering at, say, 6 AM, you are unlikely to have enough carcasses to immediately load and start your BF chamber. So your first BF chamber will commence a couple of hours later, let us say, at 8 AM.

Likewise your last BF chamber will be emptied a couple of hours after the slaughter line stops for the day. There

Profiling Central Refrigeration Plant Loads By Operating Time Intervals For The Workday		
A		B
Running time of blast freezer 1		
Running time of blast freezer 2		
Running time of blast freezer 3		
Blast Freezer 1		KW
Blast Freezer 2		KW
Blast Freezer 3		KW
Total load		
Power consumption		
Total compressor running		
Total booster load		
System -3 °C		
Running time, corridor dispatch & loading		
Running time, packing and cutup hall		
Running time, chilled water @ 14°C		
Running time, chilled water @2°C		
Running time, plant room		
Running time, fresh air AHU		
Corridor dispatch & loading		KW
Packing & cutup hall		KW
Chilled water @ 14°C		KW
Chilled water @2°C		KW
Plant room		KW
Fresh air AHU		KW
Total load		
Power consumption		
Total compressor running		
System -27 °C		
Running time, freezer room 1		
Running time, freezer room 2		
Running time, freezer room 3		
Running time, chilled store		
Running time, flake Ice		
Frozen store 1		kW
Frozen store 2		kW
Chilled store		kW
Flaker 1		kW
Total Load		
Power consumption		
Total compressor running		
Table 36 Showing template to be handed over to your refrigeration system vendor for designing the central ammonia based refrigeration plant. For more information on sections of your plant design that require to be hooked into the central design, refer Chapters 3 to 5 of this Handbook and sample layout drawings bundles with AptecAPP		



is therefore a shift lag in the freezing section of your plant. Factor this well in your plans. Use table 37 to plan this.

Although your slaughter shift may have a planned duration of 9 hours, you will only be able to fit at most two freezing cycles per BF chamber within this period, because a freezing cycle lasts around 4.5 hours – four hours for actual blast freezing and half an hour for loading and unloading the chamber. And when you consider the staggering, you will discover that with a 3 BF chamber configuration, you may achieve as few as 5 cycles within a 9-10 hour freezing shift. In order to improve the utilisation of your freezing equipment and consequently your investment in it, you must achieve rather more freezing cycles from it. Maybe a freezing shift of 15 hours might give you a reasonable number of freezing cycles from your investment. Figure it out for yourself, given your particular circumstances.

Your redrafting of table 37 will allow you to fit the required number of freezing cycles and thus arrive at the freezing shift duration and its commencement and closure times. This in turn will help you instruct your refrigeration system vendor to complete the template in table 36 satisfactorily. It will also, by a process of reiteration, enable you to choose the optimum number and size of blast freezing chambers.

Now assuming that with all the above steps you and your vendor have collectively arrived at, say, a 14 hour freezing shift length. At this stage, inform your vendor that from time to time you will operate the shift for not just 14 hours, but say, 19 hours in an effort to obtain an additional 3-4 freezing cycles per day. This then will give you a peaking capacity for freezing for use when live bird prices crash. Finally, even after packing in the increased number of freezing cycles you may find that the total does not match the tonnage of frozen poultry that your plant capacity needs. At this point you may consider designing larger chambers or diverting some products (like deboned thighs, wings and breasts) to plate freezing. In other words, reiteration is absolutely essential for optimizing operating shift duration, starting time and chamber design for your specific needs – there is no single magical solution.

Planning your BF schedule			
Chamber occupancy	Occupancy duration of chambers		
	Batch	Enters at	Exits at*
Chamber 1	Batch 1	0800	1230
Chamber 2	Batch 2	1000	1430
Chamber 3	Batch 3	1200	1630
Chamber 1	Batch 4	1400	1700
Chamber 2	Batch 5	1600	1900
Chamber 3	Batch 6	1800	2300
Number of batches per day			6
Duration of freezing per day (hours)			14**
<i>Table 37</i> Staggering of freezing cycles in a poultry processing plant with 3 BF chambers. Slaughter shift commences at 0600 hrs and ends at 1300 hrs. First freezing chamber begins at 0800 hrs and after cleaning & moving carcasses to the frozen store, the BF staff leave at 2100 hrs. During that period defrosting occurs. Freezing cycles are 4 hours + 30 minutes (for loading and unloading*). You can safely assume 5 freezing cycles on normal days, with 2-3 extra cycles on peak load days.			

13.3 How To Design BF Chambers

13.3.1 Air Flow

In a refrigerator you are advised not to pack products too tightly. Why? Because air movement inside it occurs only due to **convection current**, which is a weak force. You must align dishes vertically in a refrigerator so as to present gaps through which air may move **vertically**. Convection currents can neither move horizontally nor through closely packed dishes. If this rule was not observed, cooling will become inefficient - there may be hot-spots and stored products would not last long.

The case for a blast freezer is the exact opposite. The BF generates a **forced flow** of cold air. It will pass horizontally – **slowing down** as it passes through reasonably closely arranged carcasses, or **rapidly** through large horizontal paths which then act like short circuits.

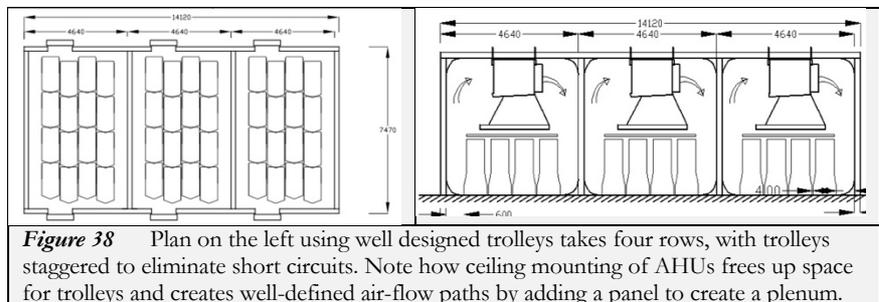


Figure 38 Plan on the left using well designed trolleys takes four rows, with trolleys staggered to eliminate short circuits. Note how ceiling mounting of AHUs frees up space for trolleys and creates well-defined air-flow paths by adding a panel to create a plenum.

When this air stream moves slowly it exhibits **turbulent flow** which is a zig-zag kind of movement. By doing so the air cools its surroundings more efficiently. On the other hand when air moves rapidly it exhibits **laminar flow**, which is a rapid, streamlined movement in which it cools nothing. So in the BF chamber you need to arrange products in such a way as to present air with plenty of horizontal passages which force it to pass close to



their surfaces in a turbulent flow. Short-circuit pathways exist between trolleys and walls of the chamber where the flow is always laminar. With laminar flow your BF chamber becomes inefficient and performs poorly.

Look at figure 38. In the picture on the left, rows of trolleys are not arranged evenly but are **staggered** so that two rows on each side have been made to reduce the distance to the wall of the chamber so as to close the short circuit paths. While in the bottom frame of figure 39 you will notice that the front of the trolley is pointed while the rear is indented so that when they are lined up, there is very little less gap between superstructures carrying stacks of carcasses. And when the rows are themselves staggered as in figure 38, all short circuits vanish altogether. So taken together, trolley design and their staggered placement fulfil the objective of creating total turbulent flow of air in the chamber.

We will now examine the placement of carcasses on the shelves of the superstructure shown on the right in figure 40. The superstructure has several rungs or shelves with floors made up of aluminium tubes rivetted to the frame at 2 inch intervals. These tubes run at right angles to the flow of air and adjacent tubes are rivetted at a slope of 2-3 degrees in such a way that carcasses lined up on them avoid leaving horizontal spaces that could allow laminar flow. So carcasses arranged on shelves cause turbulence within and between rungs, within each superstructure while adjacent rows of trolleys cause turbulence because they are staggered. This creates air turbulence at all levels - which is exactly what we want. Ask Aptec to mail a detailed structural design of the trolley shown in figure 40 so that you can understand these concepts fully.

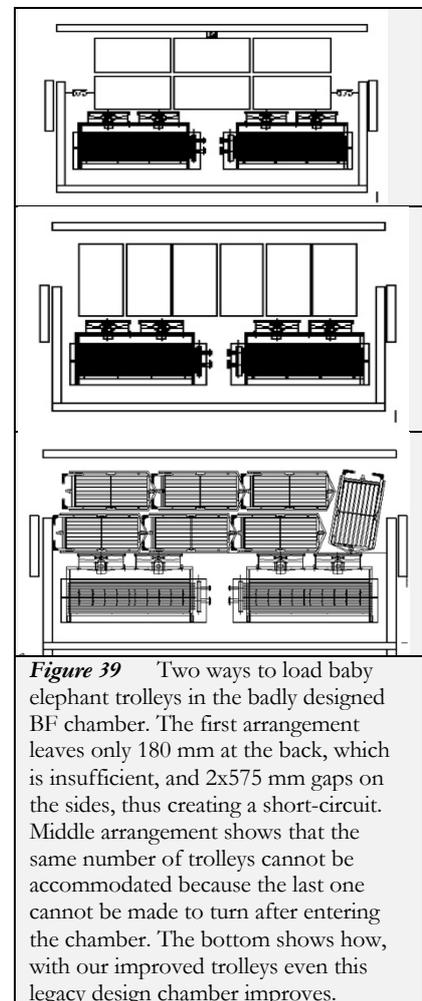
3.3.2 Chamber Design

Now let us return to figure 37 and examine the picture on the right. Here, by the addition of a sheet of insulating panel below the refrigeration evaporator and above the line-up of trolleys, thereby closing the space between them, we have created a **directed flow-path** for air through a **plenum** (or chamber in which air can be confined or made to flow through). Air is now made to follow a wide, circular path. As the arrows show, air is sucked into the evaporator, pushed out of it and made to flow **through** the line-up of carcass-loaded trolleys below. Had we not placed a sheet of panel in between, some of the air forced out of the evaporators would have immediately taken the short-cut path to the back of the evaporator and avoided the line-up of trolleys. The BF chamber would then have functioned poorly.

From this discussion you might have observed that proper functioning of a BF requires not only its proper design but also proper stacking of carcasses on trolleys and their proper placement in it and use of properly designed trolleys.

Now let us look at figure 39. Both trolley and chamber actually exist and have been drawn to scale here. Trolleys in this case are large SS platforms with evenly spaced SS sheet shelves, mounted on four swivel castors. Since the chamber was designed and sized for 4 tonnes of payload per charge (as per the vendor's design calculations), each trolley must carry a minimum load of 670 kg. This load figure is derived by back-calculating from the claimed throughput ($4000/6=667$). Because they are large and must carry such a heavy load, we call them **baby elephant** trolleys. We will now examine how the shape and size of the BF chamber and BF trolley affects performance.

The top two frames in figure 39 show two ways to stack these baby elephant trolleys. Here the BF chamber design took no cognizance of trolley design, so you can see that there is no way to reduce the short-circuit path for air adjacent to the line-up of trolleys and chamber walls. Besides, since the trolleys are evenly shaped, there are short-circuit paths between trolleys. Here because of inefficient trolley design and mismatch with chamber size and shape, regardless of how you stack carcasses and trolleys, inefficiencies will remain. But, note how the bottom frame in figure 39 shows that with trolley design of figure 40 you can improve matters.



13.3.3 FIFO

There are two ways to arrange your BF chambers. They may be lined up as a series of rooms with a single door for both taking in and withdrawing trolleys, or as a series of through-chambers with doors on opposite sides so that they act as a line-up of **first-in-first-out** freezing chambers. In the latter arrangement loaded trolleys are driven in and positioned, starting from the exit door and working backwards to the entry door till the last wheeled-in trolley gets positioned close to the entry door and all of them arranged so as to remove short-circuit paths.

When you attempt to unload the chamber, you begin by opening the exit door and withdrawing trolleys one by one till you have emptied the chamber. What do you observe? The first trolley that you wheeled in was also the first to be wheeled out and the last trolley you wheeled in was the last trolley to be wheeled out. This is the FIFO arrangement. Positioning your BF chambers in this fashion reduces traffic jams. In this arrangement all entry doors line up close to the end of the primary packing department and all exit doors line up close to the secondary packing area and the frozen stores.

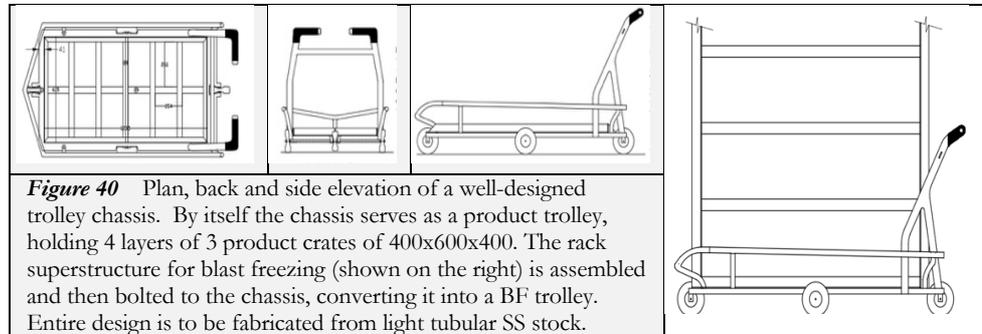


Figure 40 Plan, back and side elevation of a well-designed trolley chassis. By itself the chassis serves as a product trolley, holding 4 layers of 3 product crates of 400x600x400. The rack superstructure for blast freezing (shown on the right) is assembled and then bolted to the chassis, converting it into a BF trolley. Entire design is to be fabricated from light tubular SS stock.

13.3.4 Trolley Design

Given a finite number of evaporator models, it is still possible to get better results if you opt for small trolleys. Such a trolley design (figure 40) has been available to the industry from October 2011 when this Author first designed and published it. Use of such a trolley makes it easy for one man to move a trolley load. Since it carries approximately 300 kilograms, it can be loaded and unloaded rapidly. You can load cartons, trays or whole carcasses on it. In addition, it is modular, having been designed with a common chassis for product transport or blast freezing application, so it is easy to standardize. The chassis design allows nestling so transport by trucks is easy. For BF application a racking superstructure is assembled and added to the chassis at site. The assembled trolley configured for BF use is shown on the extreme right. To retain stability it cannot be made as tall as a baby elephant trolley but you can achieve eight shelves of carcasses, although only four are shown here.

13.3.5 Evaporator Design – Width & Mounting Style

Two features of the evaporator design available with your refrigeration system vendor affect your BF design. These are the **mounting style** and the **width** of evaporator models available with him. Evaporators may be floor mounted, on top of steel or concrete foundations, raised sufficiently as to allow air flow and trolley loads to be at the same level. Alternatively they may be suspended from the ceiling. In the case of suspended evaporators, the vendor will make use of a steel structure erected on the floor. Here since the roof of the hall is typically of the truss-steel sheet design and cannot take any meaningful load, it cannot be made use of for suspension, although suspended evaporators are typically lighter in construction. Suspended and floor-mounted evaporators have been shown in figures 38 and 39 respectively.

With suspended evaporators you get more trolley parking space. Some of our vendors lack the expertise for designing and installing suspended evaporators, or are too lazy to apply their minds, or want to continue selling old fashioned heavy floor mounted evaporator models. Light weight suspended evaporators may be imported, but they cost more. When making a choice do you compare the cost efficiency or just the one-time cost? If the latter, you end up paying more over the long run. When you design your BF chambers, also make sure to consult your vendor about the standard width of his evaporator models. Unless the chamber is designed taking both evaporator width and trolley line-up into account, there will be plenty of gaps through which airflow will short circuit and you will have an inefficient BF chamber.

For example, assume that the available evaporator is 2573 mm wide, and your chamber width is 5750, (as they are in figure 39), you will fit two of them side by side for baby-elephant trolleys, which are 800x1500. You will then



have plenty of short-circuit pathways. Further, given this combination of dimensions, no matter how you stack your trolleys inside the chamber, there will be plenty of gaps or short-circuit paths. Therefore you should begin designing the system by first taking the factors that are given in your case – suspension style and standard width of evaporators that your vendor can supply. Using the available chamber width now determined by the evaporator width (with two or three of them lined up side by side), you now have the dimension of the long side of the BF chamber. Place 3-4 rows of the BF trolleys before the evaporator line-up (if the evaporators are floor-mounted or on top of the evaporator line-up if they are suspended), and you now have the width dimension of the chamber. Multiply the number of trolleys, payload/trolley and the number of charges available in a 15 hour period and you have your plant's overall BF capacity in tonnes per charge.

To sum up, the BF capacity that can be built on a given floor space depends on (1) evaporator width and its suspension system, (2) BF trolley design and number of rows that can be lined up, and (3) the number of freezing cycles that you can achieve from around 15 hours of operation, leaving some 6-7 hours spare each day for peaking loads.

If you find the calculated number of freezing cycles per day insufficient, go back and perform the exercise with different evaporator models and different BF chamber widths. When you have achieved the best BF chamber design, place it in your plant layout drawing and leave some space for adding one or two identical BF chambers for future expansion.

13.3.6 Refrigerant

As mentioned above, the refrigeration system for the BF must be ammonia based. However, since ammonia is toxic, if required by law, it is often necessary to adopt a secondary refrigerant (which is approved for contact with food), which is cooled by ammonia. This secondary refrigerant is then circulated through the evaporator tubes. In doing this, any chance of leaked ammonia coming into contact with meat is avoided. The typical secondary refrigerant is **propylene glycol**⁵². Another method to prevent the leakage of ammonia in the secondary processing areas in a slaughterhouse is to securely weld all pipe joints and valves that are within that area.

13.3.7 BF Doors

Although all the BF chambers in this document show sliding doors, the best doors to be used are hinged. Sliding doors do not seal well whereas hinged doors have a positive and firm sealing action. Therefore for BF chambers hinged doors are best.

13.3.8 Other Preferred Features Of Central Refrigeration

Central Plant

It makes a lot more sense to opt for a central refrigeration plant based on ammonia, complete with low and high stages, with secondary refrigerant if needed. In addition one or more of your frozen stores may be based on HFC/CFC because frozen stores need to work on Sundays and holidays and it would be unwise to make the entire central plant work for such trivial loads on these days. Configuring separate compressors with each load is a bad idea because it results in idle capacity, under-utilisation of capacity and prevents you from having standby compression capacities. Small refrigeration shops are restricted to this kind of designs because they lack the technical expertise to design and install central plants. Table 36 explains how to profile total load for a central plant.

Waste Heat Recovery

New technologies are available for recovering useful energy from absorption chilling with lithium bromide from the boiler (where steam is cheap or surplus), or from the evaporative condenser line in refrigeration circuits. For central refrigeration plants this can result in lots of savings. Do consider specifying waste heat recovery in your tender.

Reciprocating or Rotary Compressors

For large and steady compression loads rotary compressors are more efficient, while for intermittent and varying compression loads reciprocating compressors are better. Your central refrigeration plant may therefore consist of a judicious mix. From table 36, your vendor should be able to specify the best combination.

Evaporators & Defrosting



Evaporators in the frozen store and blast freezers will need frequent defrosting to clear them of ice and restore their efficiency. Use of hot gas is the best method for it. When specifying space cooling down to +12°C for the packing and portioning spaces and +8°C for the despatch corridor, be sure to specify an appropriate refrigerant. In our experience circulated chilled water does not meet the requirement satisfactorily.

Setting Up An Engineered Ventilation System

Chapter 4 shows how you need to inject a steady stream of over-pressure refrigerated air into the cut-up and packing hall to establish a unidirectional flow of air throughout your plant in the interest of product quality and workers' comfort and health. Your vendor needs to be instructed to incorporate this in his design.

Safety

At a sufficient level of concentration ammonia is combustible as you will have learnt from Chapter 5. Therefore a central refrigeration plant based on ammonia is always a fire hazard. Ensure that your vendor observes all rules associated with ammonia in his bid. Ensure also that the central plant building is separated from the process plant by a road which can allow a fire tender to enter. Refer Chapter 5 to understand these well established design, construction and operation rules and discover how flouting them may result in disaster.

14 Plate Freezing

Two types of plate freezers (figure 41) are in use. The vertical machine is used for block-freezing of mechanically deboned poultry (MDM). The material is dropped into the several vertical slots and the blocks are then frozen. After the blocks are frozen, the plates are separated a bit and they are pulled out, and then packed individually in cartons and shipped to RTE plants to be blended and turned into sausages or nuggets. In the horizontal type of machine, sachets of deboned meat in large packs (kilogram packs typically) are frozen and sold to institutional buyers. In these machine the plates are hydraulically operated to create spaces. Once the machine is loaded (typically 2 tonnes), the hydraulically operated plates are brought together and the machine goes into operation, eventually freezing all the packs into bricks of deboned meat or MDM in 2 hours or so.

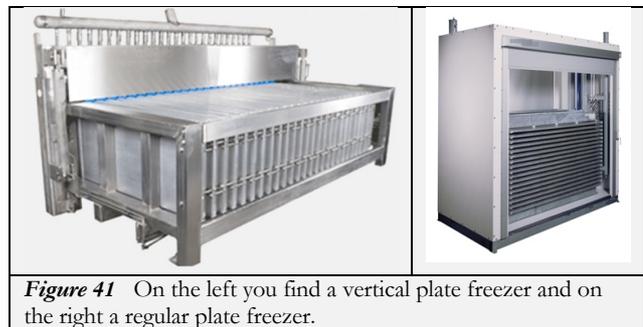


Figure 41 On the left you find a vertical plate freezer and on the right a regular plate freezer.

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Endnotes

- ¹ The body temperature of adult chicken ranges between 40.6°C and 41.7°C. According to the University of Kentucky, newly hatched chicks have a slightly lower body temperature of around 39.7°C, which gradually increases to the adult level over the first few weeks of life.
- ² Facts Sheet on Poultry Preparation, last modified: April 4, 2006.
- ³ Food And Agriculture Organization Of The United Nations, Rome, 1994 Regarding mechanism of freezing meat. Torry, Aberdeen, Scotland, UK.
- ⁴ The choice of -18°C for frozen storage may have been quite arbitrary, influenced probably by the fact that it roughly equals 0°Fahrenheit, the scale which preceded the Centigrade scale in popular usage by some 18 years and might therefore have had a “*magical ring of truth*” about it! Temperatures considerably above -18°C are equally capable of preserving food nearly as well!
- ⁵ Blast Freezing Applications in Conventional Rooms, Naci Şahin, Mechanical Engineer General Manager, Friterm, Termik Cihazlar Sanayi ve Ticaret A.S.
- ⁶ Efficient cooling of meat (or any other substance, for that matter), depends on two factors (1) the temperature difference between the meat (being cooled) and water (the medium doing the cooling). This must be substantial – certainly larger than 2 Celsius degrees; and (2) this cooling rate reduces as the temperature difference falls and consequently the rate of heat exchange takes *substantially* longer when these two temperatures are too close to each other.
- So when you use water as the chilling medium, you cannot chill it down below +2°C and the meat that you attempt to cool with this water cannot come down to +4°C except when the process stretches for hours. Why can you not chill water down to a lower temperature? Because when water freezes, it expands, and when it does so, it bursts the pipe it flows in. So to be on the safe side engineers do not design chilling equipment using chilled water to perform below +2°C. **Do not let your refrigeration equipment vendor makes claims to the contrary!** Consequently when you use water as a chilling medium, you cannot set a practical chilling target down to +4°C
- ⁷ Basic Principles Of Cryopreservation. Cryo-conservation of animal genetic resources. Section 7. Food and Agriculture Organization <https://openknowledge.fao.org>.
- ⁸ Freezing of water which contains dissolved substances results in ice which contains little or no dissolved substances or impurities. Which is why you can drink the water obtained by thawing pieces of icebergs when sailing the seas. In fact by successive steps of freezing and thawing of water, you end up obtaining purer and purer water with each freeze-thaw cycle. This process of successive freezing and thawing is a well recognized engineering process of purification called *zone refining* and is used in the production of ever purer materials with wide application in several fields, including production of ultra-pure silicon for electronics.
- ⁹ *Ibid.* Basic Principles Of Cryopreservation Of Animal Genetic Material.
- ¹⁰ Just as the addition of salt to a slush of ice and water could lower the freezing point and allow you to make ice cream by the old ice bucket system.
- ¹¹ Some fish freeze at well below the freezing point of water because of the presence of anti-freeze compounds within their cells. Unlike fresh water, which freezes at 0°C, sea water freezes at -1.8°C. So for marine fish presence of antifreeze compounds in their cells is an important evolutionary adaptation.
- ¹² What happens during freezing. <https://www.fao.org/4/v3630e/v3630e03>.
- ¹³ Control of Foodborne Microorganisms. by Vijay K Juneja and John N Sofos.
- ¹⁴ Chirality is the name given to right and left handedness of three dimensional entities. Your two hands are mirror-images of each other but these mirror images cannot be fused into each other. The hands of a mechanical clock, design of screw threads and countless three dimensional objects exhibit chirality.
- ¹⁵ In this Handbook we have taken as standard a temperature of +2°C as the inlet water temperature in immersion cooling. Maintaining it 2 Celsius degrees above zero is for safety. Why do we need a safety margin? Because when water flows within a pipe, there are strong chances that at some places within the delivery pipe statistical variations caused by flow may cause local dips in temperature and initiate the freezing process to form plugs of ice.
- ¹⁶ Rutherford or Lord Kelvin, (after whom Absolute Zero is pegged as 0°K), and countless others have been involved in demystifying these facts. Even our Nandlal Bose of undivided India worked with Einstein to formulate the Bose-Einstein condensate hypothesis, the absolute zero state of matter. In discovering these facts and mysteries scientists remain at work today.
- ¹⁷ Human *Campylobacteriosis* Epidemic in Iceland 1998- 2000 and Effect of Interventions Aimed at Poultry and Humans. FAO/WHO Global Forum of Food Safety Regulators Marrakech, Morocco, 28 - 30 January 2002 by Reiersen J, Briem H, Hardardottir H, Gunnarsson E, Georgsson F, Gudmundsdottir E, Kristinsson KG.
- ¹⁸ Moisture Content, Processing Yield, And Surface Colour Of Broiler Carcasses Chilled By Water, Air, Or Evaporative Air By J.Y. Jeong, K.K. Janardhanan, A.M. Booren, D.M. Karcher, I. Kang. 2011
- ¹⁹ The Big Thaw, USDA. Safe Defrosting [https://www.fsis.usda.gov/food safety/safe food handling and preparation/food safety basics/big thaw safe defrosting methods](https://www.fsis.usda.gov/food%20safety/safe%20food%20handling%20and%20preparation/food%20safety%20basics/big%20thaw%20safe%20defrosting%20methods).
- ²⁰ Cryofreezing. Clyde L. Rasmussen2 [119]
- ²¹ Morris Brochure: Quick Chill With High Capacity Auger Chiller.
- ²² Young and Smith, 2004 report moisture gain of up to 11.7%.
- ²³ Bells & Evans leaflet <https://www.bellandevans.com/our-story/>



²⁴ Only so high as to not present a slip gap large enough for carcasses to slip in the reverse direction, a tendency that would increase when carcasses get crowded.

²⁵ Compliance Guidelines for Controlling *Salmonella* in Small and Very Small Plants that Produce Raw Poultry Products, Patricia A. Curtis, Professor & Director, Auburn University Poultry Products Safety Notice entitled, “*Salmonella* Verification Sample Result Reporting: Agency Policy and Use in Public Health Protection (71 FR 9772) on February 27, 2006 (<http://www.fsis.usda.gov/OPPDE/rdad/FRPubs/04-026N.pdf>)& Quality Peaks of Excellence Program. FSIS published a *Federal Register*.

²⁶ The Effect of Chilling in Cold Air or Ice Water on the Microbiological Quality of Broiler Carcasses and the Population of *Campylobacter* M. E. Berrang, R. J. Meinersmann, D. P. Smith, and H. Zhuang USDA-Agricultural Research Service-Russell Research Centre, 950 College Station Rd., Athens, GA 30604 (2004). This reference was contributed by brought to our notice by Peter Kragtjik, refrigeration expert at Meyn

²⁷ The FSIS, in its article dated 01/09/200, entitled Retained Water in Raw Meat and Poultry Products; Poultry Chilling Requirements Docket No. 97-054F, 9 CFR 3819 CFR 441

²⁸ USDA Facts Sheet on Poultry Preparation, Last Modified April 4, 2006. Food safety requirements which should be met and which should be included in a retained water protocol include the applicable salmonella performance standards as described in Ch. 11, US section, Annex U.

²⁹ Water absorption and dripping of chicken breast and carcasses during pre-cooling in an industrial system by Elidiane Lorenzetti , Bruna Maria Saorin Puton, Ilizandra Aparecida Fernandes, Naimara Vieira do Prado, Rudson Frigotto, Silvane Souza Roman, Alexander Junges, Clarice Steffens, Jamile Zeni, Juliana Steffens, Geciane Toniazco Backes, Rogério Luis Cansian, Eunice Valduga. Published in Poultry Science Volume 97, Issue 12, 1 December 2018

³⁰ [Http://www.eng.auburn.edu/~wfgale/usda_course/](http://www.eng.auburn.edu/~wfgale/usda_course/)

³¹ This Author has had a real-life experience on this principle. On his advice, Mr Kishore Hegde, owner of a locally fabricated plant at Chikmagalur modified his screw chiller sometime around 2012 by reversing the con-current direction cooling into counter-current cooling. The chiller’s performance improved so dramatically that he retained the machine when he switched over from the locally fabricated plant to Meyn in 2013. It remains in operation to this day and is perhaps the only locally fabricated screw chiller in India which was corrected. All others were designed and built wrong and remain faulty, inefficient and wasteful.

³² Contribution by Dr Shashidhar Ramachandra

Thermodynamic Analysis of Air Agitation in Poultry Screw Chillers: Busting the Myth of Significant Water Heating	
Theoretical Calculations by Shashidhar Ramachandra for APTEC September 17, 2025	
<p>This technical report, using two independent methods (compressor power consumption analysis & sensible heat transfer calculation) presents a comprehensive thermodynamic analysis disproving the persistent myth that compressed air agitation significantly heats water in poultry immersion chillers. We demonstrate that the maximum theoretical temperature rise is less than $0.7^{\circ}\text{C}/\text{h}^{-1}$ under extreme assumptions, and realistically below $0.3^{\circ}\text{C}/\text{h}^{-1}$. These values represent less than 0.4% of the total cooling load, which is negligible compared to the substantial benefits of air agitation.</p> <p>Nomenclature A = Area (m^2); C_p = Specific heat capacity at constant pressure ($\text{kJ}/\text{kg K}^{-1}$); D = Diameter (m); E = Energy (kJ); L = Length (m); \dot{m} = Mass flow rate (kg s^{-1}); P = Pressure (kPa); Q = Volumetric flow rate ($\text{m}^3 \text{s}^{-1}$) or Heat transfer rate (kJ s^{-1}); r = Radius (m); T = Temperature (K or $^{\circ}\text{C}$); t = Time (s); V = Volume (m^3); γ = Ratio of specific heats (C_p/C_v); ρ = Density (kg m^{-3}); Δ = Difference operator</p> <p>Despite its operational importance, a persistent myth exists among poultry processing professionals: that the heat of compression from air compressors negates the cooling benefit by significantly warming the chilling medium. What follows is a rigorous thermodynamic analysis quantifying the actual thermal impact of compressed air injection. Using fundamental physical principles and realistic operational parameters, we demonstrate mathematically that the heating effect is negligible.</p>	
<p>Thermodynamic Analysis Method The First Law of Thermodynamics, also known as the principle of energy conservation, states that energy cannot be created or destroyed, only transformed from one form to another. For a control volume, this is expressed as:</p> $\dot{Q} - \dot{W} = \frac{dE}{dt} + \sum \dot{m}_{\text{out}} h_{\text{out}} - \sum \dot{m}_{\text{in}} h_{\text{in}} \tag{3.1}$ <p>where \dot{Q} is heat transfer rate, \dot{W} is work transfer rate, dE/dt is the rate of change of energy within the control volume, and $\dot{m}h$ represents the enthalpy flow rates across the control volume boundaries.</p> <p>Adiabatic Compression Principle For centrifugal compressors operating rapidly with minimal heat transfer to surroundings, the compression process can be modelled as adiabatic (no heat transfer) and reversible (isentropic). The relationship between pressure and temperature for an ideal gas undergoing isentropic compression is given by:</p> $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} \tag{3.2}$ <p>where T_1 and T_2 are initial and final temperatures, P_1 and P_2 are initial and final pressures, and γ is the ratio of specific heats (C_p/C_v).</p> <p>System Definition and Parameters All calculations presented in this analysis are based on a standard 6-meter section of a horizontal screw chiller with operational parameters derived from industry standards and fundamental thermodynamic properties. Here Chiller diameter (D) = 2.1m; Chiller radius ($r = D/2$) = 1.05m; Section length (L) = 6m; Compressor power (P_{comp}) = 3kW; Air volumetric flow rate (Q_{air}) = $320 \text{ m}^3 \text{ h}^{-1}$ (at standard conditions: 0°C, 101.325kPa); Ambient air temperature (T_{inlet}) = 35°C (308.15K); Chilling water temperature (T_{water}) = 0°C (273.15K); Discharge pressure ($P_{\text{discharge}}$) = 150kPa absolute (approximately 0.5bar gauge pressure); Inlet pressure (P_{inlet}) = 101.325kPa absolute.</p>	



<p>Material Properties - Specific heat of water ($C_{p,water} = 4.186 \text{ kJ kg}^{-1} \text{ K}^{-1}$); Specific heat of air ($C_{p,air} = 1.006 \text{ kJ kg}^{-1} \text{ K}^{-1}$); Ratio of specific heats for air ($\gamma = 1.48$); Density of air at standard temperature and pressure ($\rho_{air} = 1.292 \text{ kg m}^{-3}$); Density of water ($\rho_{water} = 1000 \text{ kg m}^{-3}$)</p>																					
<p>Water Volume Calculation The chiller is modelled as a partially filled horizontal cylinder. The fill level is specified to be at the "hemi-cylinder" level, with correction for the volume occupied by the central drive shaft and screw assembly. The cross-sectional area of a half-cylinder is given by: (4.1) $A_{half} = 1/2 \pi r^2 = 1/2 \pi (1.05)^2 \approx 1.732 \text{ m}^2$ The cross-sectional area occupied by the drive shaft assembly (conservatively estimated for shaft and supports with diameter $d = 0.3 \text{ m}$) is: (4.2) $\pi(0.3/2)^2 = \pi(0.15)^2 \approx 0.0702 \text{ m}^2$ where $A_{shaft} = 0.0702 \text{ m}^2$ (4.3) The effective water cross-sectional area is therefore: $A_{water} = A_{half} - A_{shaft} \approx 1.732 - 0.071 = 1.661 \text{ m}^2$ (4.4) The water volume for the 6-meter section is: $V_{water} = A_{water} \times L = 1.661 \times 6 \approx 9.97 \text{ m}^3$ (4.5) The corresponding water mass is: $m_{water} = V_{water} \times \rho_{water} = 9.97 \times 1000 = 9970 \text{ kg}$</p>																					
<p>Compressor Power Consumption Analysis Method This method applies the First Law of Thermodynamics (conservation of energy) to calculate the maximum possible temperature rise assuming 100% of the electrical energy consumed by the compressor is converted to thermal energy and absorbed by the water bath. This represents a conservative (pessimistic) assumption, as in reality some energy is lost as sound, vibration, and heat dissipated from the compressor body.</p>																					
<p>Mathematical Formulation (5.1) The total energy input per hour is: $E_{input} = P_{comp} \times \Delta t = 3 \text{ kJ s}^{-1} \times 3600 \text{ s} = 10800 \text{ kJ h}^{-1}$ (5.2) Heat capacity of water bath (energy reqd to raise its temp by 1°C) is: $C_{bath} = m_{water} \times C_{p,water} = 9970 \text{ kg} \times 4.186 \text{ kJ kg}^{-1} \text{ K}^{-1} \approx 41740 \text{ kJ K}^{-1}$ (5.3) The maximum possible temperature rise is therefore: $\Delta T_1 = E_{input} / C_{bath} = 10800 / 41740 \approx 0.26 \text{ }^\circ\text{C}$</p>																					
<p>Conclusion Even under the conservative assumption that all electrical energy consumed by the compressor is converted to heat within the water bath, the temperature rise is limited to approximately $0.26 \text{ }^\circ\text{C h}^{-1}$. This represents a realistic upper-bound estimate of the heating effect.</p>																					
<p>Sensible Heat Transfer from Air This method calculates the theoretical maximum heat transfer from the compressed air to the water by determining the temperature of the air after compression and the heat it would release, upon cooling, to the water. This approach assumes ideal conditions: 100% efficient compression and 100% effective heat transfer from air bubbles to water.</p>																					
<p>Mathematical Formulation The mass flow rate of air is: $m_{air} = Q_{air} \times \rho_{air} = 320 \text{ m}^3 \text{ h}^{-1} \times 1.292 \text{ kg m}^{-3} = 413.4 \text{ kg h}^{-1}$ (6.1) The discharge air temperature is calculated using the adiabatic compression equation for a centrifugal compressor: $T_{discharge} = T_{inlet} \times (P_{discharge} / P_{inlet})^{(\gamma-1)/\gamma} = 308.15 \text{ K} \times (150 / 101.325)^{0.4/1.4}$ (6.2) $T_{discharge} = 308.15 \text{ }^\circ\text{K} \times (1.480)^{0.2857} \approx 308.15 \text{ K} \times 1.116 = 343.9 \text{ }^\circ\text{K} (70.75^\circ\text{C})$ (6.3) The available sensible heat (enthalpy change) when discharging air cools, to water temperature is: $Q_{sensible} = m_{air} \times C_{p,air} \times \Delta T_{air} = 413.4 \text{ kg h}^{-1} \times 1.006 \text{ kJ kg}^{-1} \text{ }^\circ\text{K}^{-1} \times 70.75 \text{ }^\circ\text{K} \approx 29430 \text{ kJ h}^{-1}$ (6.4) The potential temperature rise is therefore: $\Delta T_2 = Q_{sensible} / C_{bath} = 29430 / 41740 \approx 0.705 \text{ }^\circ\text{K h}^{-1} \approx 0.71 \text{ }^\circ\text{C h}^{-1}$ (6.5)</p>																					
<p>Conclusion of Sensible Heat Transfer Method This method provides a strict theoretical maximum temperature rise of $0.71 \text{ }^\circ\text{C h}^{-1}$, which represents an upper bound under ideal conditions. In practice, compressor inefficiencies and imperfect heat transfer would result in a lower actual temperature increase.</p>																					
<p>The results from both methods are summarized here. To properly contextualize these values, they must be compared to the primary heat load on the chiller's refrigeration system—the energy required to cool the carcasses themselves.</p>																					
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<p>Primary Cooling Load Calculation The primary load is derived from cooling the poultry carcasses. For a modern processing line with the following parameters: Throughput: $N = 6,000 \text{ bird h}^{-1}$ Average bird mass: $m_{bird} = 1.3 \text{ kg bird}^{-1}$ Temperature reduction: $\Delta T = T_{initial} - T_{final} = 35 - 4 = 31 \text{ }^\circ\text{K}$ (7.1) Specific heat of poultry meat: $C_{p,meat} = 3.0 \text{ kJ kg}^{-1} \text{ K}^{-1}$ The heat removed per bird is calculated as: $Q_{bird} = m_{bird} \times C_{p,meat} \times \Delta T = 1.3 \times 3.0 \times 31 = 120.9 \text{ kJ bird}^{-1}$ (7.2) The total primary energy load/hr is therefore: $Q_{primary} = N \times Q_{bird} = 6000 \times 120.9 = 725400 \text{ kJ h}^{-1}$ (7.3) This energy rate can be expressed as an equivalent power requirement: $P_{primary} = Q_{primary} / 3600 = 725400 / 3600 \approx 201.5 \text{ kW}$ (7.4)</p>																					
<p>Agitation Load as a Percentage of Primary Load The additional thermal load from air agitation is now expressed as a percentage of this primary load. For Method 1: Percentage Increase₁ = $(E_{ag1} / Q_{primary}) \times 100\% = (10800 \text{ kJ h}^{-1} / 725400 \text{ kJ h}^{-1}) \times 100\% = 1.49\%$ (7.5) Power Increase₁ = $(P_{ag1} / P_{primary}) \times 100\% = (3.00 \text{ kW} / 201.5 \text{ kW}) \times 100\% \approx 1.49\%$ (7.6) For Method 2: Percentage Increase₂ = $(E_{ag2} / Q_{primary}) \times 100\% = (29430 \text{ kJ h}^{-1} / 725400 \text{ kJ h}^{-1}) \times 100\% \approx 4.06\%$ (7.7) Power Increase₂ = $(P_{ag2} / P_{primary}) \times 100\% = (8.18 \text{ kW} / 201.5 \text{ kW}) \times 100\% \approx 4.06\%$ (7.8)</p>																					
<p>Conclusion of Comparative Analysis Both values—1.49% (realistic) and 4.06% (theoretical maximum)—are well within the standard design safety factor of 10% to 20% for industrial refrigeration systems. This confirms that the thermal contribution from air agitation is a negligible addition to the total system load and is effectively insignificant in the overall energy balance of the chiller.</p>																					



³³ Extensive bird-to-bird contact via immersion chilling was claimed to result in pathogen cross-contamination to other carcasses (Bailey et al,1987).

³⁴ In the poultry industry airborne microflora is dominated by spherical bacteria, and the viable bacteria consist mainly of *Staphylococcus* spp. and *Micrococcus* spp. The concentrations of viable fungi represent approx. 0.01% of the total viable count. The principal fungal genera have been identified as *Penicillium*, *Aspergillus*, *Paecilomyces*, *Geotrichum* and *Rhizopus* (Nielsen & Breum, 1995).

The microbial flora measured with the MD8 sampler in a study by Fries and Graw (1999) consisted mainly of *streptococci*, *micrococci*, *staphylococci*, *corynebacteria*, *bacilli*, *lactobacilli* and *enterobacteria* originating from the carcasses, water and soil. Invisible aerosols in the poultry process have been shown to contain up to 6.3 log CFU/ml. The air samples were found to contain primarily *micrococci* and Gram-positive irregular rods (Fries & Graw, 1999). Ellerbroeck (1997) sampled the air in chillers and found that the mean load was 3.3 log CFU/m³ in a dry-chilling system and 4.2 log CFU/m³ in a chilling system using water sprays. Rahkio and Korkeala (1997) showed that there was no difference in the airborne bacterial loads in a slaughterhouse between those determined in the morning and in the afternoon. The microbial load of the air is influenced by the building design and airflow system.

Aerial dispersion of microbes occurring in the chillers appears to cross-contaminate carcasses. This can occur during air-chilling of poultry both with and without water sprays incorporated (Mead et al., 2000).

³⁵ All international standards that we at Aptec have come across relate 2.5 litres of water to a kilogram of carcass weight except Indian standards which relates 2.5 litres to one eviscerated carcass (carcass weight variations among different breeds was apparently considered irrelevant because of the confidence the BIS advisors felt in the permanence of Ven-Cobb-100, a very small bird that almost never yielded more than a 1200 grams after dressing).

³⁶ This Author has faced a situation in which a client insisted on introducing air chilled poultry in India around 2012 without bothering to educate consumers who were utterly unfamiliar with it. The Indian poultry market has of late been (quite slowly and reluctantly) transitioning from the wet market to factory processed poultry and expects all fresh poultry carcasses to be dripping wet. So, when his air-chilled poultry appeared in the marketplace, customers refused to buy it, feeling that the excessive dryness represented several years of frozen storage. Surely, something so dry could not claim to be called **fresh**-chilled!

The owner of the plant then tried to turn the fogging system into an **evaporative** air chilling system by spraying water on carcasses, upon which the tunnel had ice deposit all over the floor, causing people to slip and fall. There were ice deposits on the overhead track drive-chain and corner wheels! The refrigeration system failed because it could not cope with the extra heat load introduced by liquid water.

³⁷ (Mielnik et al. 1999; James et al. 2006; Jeong et al. 2011a; Demorik et al. 2013)

³⁸ (Barbut 2010; Jeong et al. 2011a).

³⁹ (Carciofi and Laurindo 2007, 2010; Carroll and Alvarado 2008; Jeong et al. 2011a)

⁴⁰ Mielnik et al. 1999; Young and Smith 2004; Savell et al 2005; Carciofi and Laurindo 2007, 2010; Huezo et al 2007; Carroll and Alvarado 2008; Jeong et al 2011a,b; Martins et al 2011; Perumalla et al 2011; Demorik et al 2013 and Paolazzi et al 2013.

⁴¹ Landfeld and Houska (2006).

⁴² India Needs Demand Based Production, Not Production Based Marketing, by K. S. Ashok Kumar, October 2022 issue of Asian Poultry.

⁴³ Air versus Water Chilling of Chicken: a Pilot Study of Quality, Shelf-Life, Microbial Ecology, and Economics Aerial D. Belk Toni Duarte, Casey Quinn, David A. Coil, Keith E. Belk, Jonathan A. Eisen, Jason C. Quinn, Jennifer N. Martin, Xiang Yang, and Jessica L. Metcalf. Published in Research Square, under a Creative Commons Attribution 4.0 International License.

⁴⁴ *Ibid.* Berrang et al.

⁴⁵ Comparison of Air and Immersion Chilling on Meat Quality and Shelf Life of Marinated Broiler Breast Fillets. C. D. Carroll, C. Z. Alvarado Poultry Science, Volume 87, Issue 2, 1 February 2008, Pages 368–372, <https://doi.org/10.3382/ps.2007-00213>.

⁴⁶ Compilation by Sharon Durham, Agricultural Research Service Information Staff, United States Department of Agriculture. Published in The Poultry Site, May 2008

⁴⁷ Chilling Of Broiler Carcasses: Microbiological And Quality Implications by Roger Ivan Huezo (Under the direction of Julie K. Northcutt of USDA)

⁴⁸ *Ibid.* Moisture Content... Jeong et al

⁴⁹ The Impact Of Chilling Methods On Microbiological Quality Of Broiler Carcasses by Peter Popelka, Monika Pipová, Jozef Nagy, Alena Nagvová, Adriana Feckaninová, Jozef Figel. *Potravinárstvo*, 2014, no. 1, p. 67-71

⁵⁰ Poultry Carcasses Chilled By Forced Air, Water Immersion And Combination Of Forced Air And Water Immersion. L.G.G. Rodrigues, B.A.M. Carciofi and J.B. LAURINDO1 Federal University of Santa Catarina, Department of Chemical and Food Engineering, Florianópolis, SC 88040-900, Brazil Journal of Food Process Engineering ISSN 1745-4530 Received for Publication March 7.

⁵¹ Although proteins are stable at the temperature of -18 degrees, fats are not. Specially unsaturated fats such as found in fatty fish and chicken. When such fats become rancid, hydroperoxides, which are the first products formed from rancidity and are stable at low temperatures damage vitamin E which is present, in the dissolved state in fats. On the other hand, hydroperoxides resulting from rancidity at ambient temperatures break down into harmless peroxides, aldehydes and ketones, so that vitamin E is more stable at room temperature than during frozen storage.

⁵² Propylene glycol's close cousin ethylene glycol is the principal additive to water in automobile radiators to raise the boiling point and lower the freezing point of water so that it does not freeze in snowy weather and works more efficiently when heated beyond the boiling point of water.

