Energy in Food Processes

The modern food processing plant cannot function without adequate supplies of basic utilities. The use of large quantities of water is not unexpected due to the handling of food in water and the need for water as a cleaning medium. Electricity is used as a utility to power many motors and related equipment throughout food processing. Heated air and water are used for a variety of purposes, with energy provided from several fuel sources, including natural gas, coal, or oil. Refrigeration is a much used utility throughout the food industry, with most applications involving conversion of electrical energy into cold air. Steam is a utility similar to refrigeration, in that its availability is dependent on generating facilities at a location near the point of use.

1. GENERATION OF STEAM

Steam represents the vapor state of water and becomes a source of energy when the change-of-state is realized. This energy can be used for increasing the temperature of other substances, such as food products, and results in production of a water condensate as the energy is released. The vapor state of water or steam is produced by addition of energy from a more basic source, such as fuel oil or natural gas, to convert water from a liquid to a vapor state.

This section will first describe typical systems used in the food industry for conversion of water to steam. The thermodynamics of phase change will be discussed and will be used to explain steam tables. The values tabulated in steam tables will be used to illustrate energy requirements for steam generation, as well as availability of energy from steam to use in food processing. The efficient conversion of energy from the source used to generate steam to some food processing application will be emphasized.

1.1. Steam Generation Systems

The systems for generation of steam can be divided into two major classifications: fire-tube and water-tube. Both systems are used in the food industry, but water-tube systems are designed for the more modern applications. The steam generation system or boiler is a vessel designed to bring water into contact with a hot surface, as required to convert liquid to vapor. The hot surface is maintained by using hot gases, usually combustion gases from natural gas or other petroleum products. The boiler vessel is designed to contain the steam and to withstand the pressures resulting from the change of state for water.

Fire-tube steam generators (Fig.1) utilize hot gases within tubes surrounded by water to convert the water from liquid to vapor state. The resulting heat transfer causes the desired change of state, with the vapors generated contained within the vessel holding the water. A water-tube steam generator (Fig. 2) utilizes heat transfer from hot gas surrounding the tubes to the water flowing through the tubes to produce steam. The heat transfer in the water-tube system tends to be somewhat more rapid because of the ability to maintain turbulent flow within the liquid flow tube.

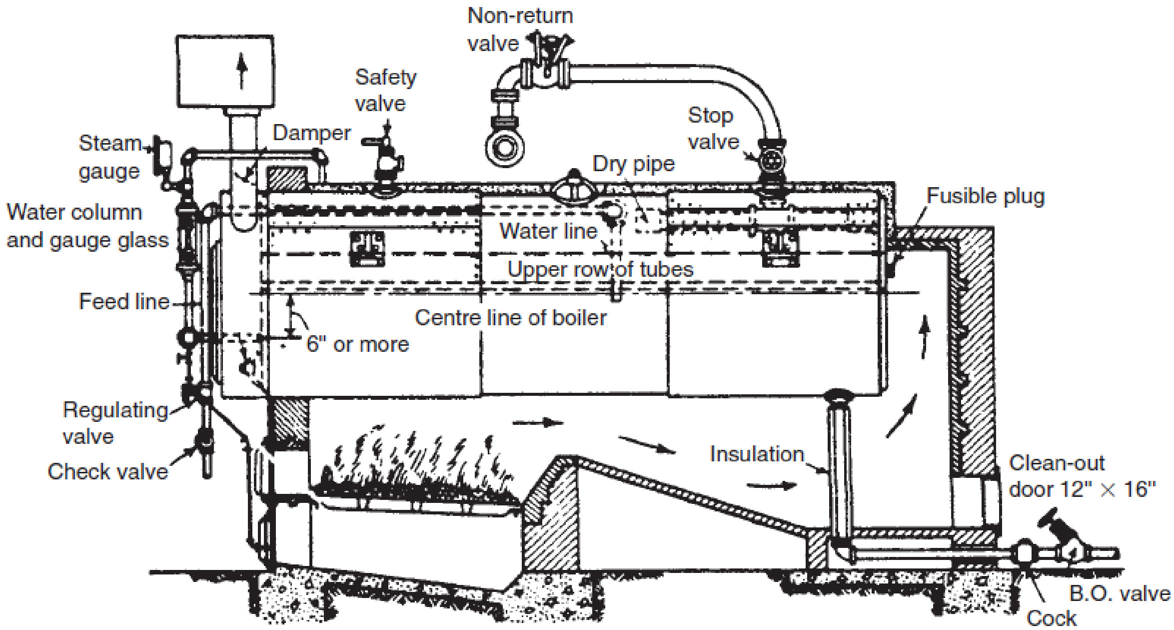

Figure 1. The horizontal return tubular (HRT) fire-tube boiler

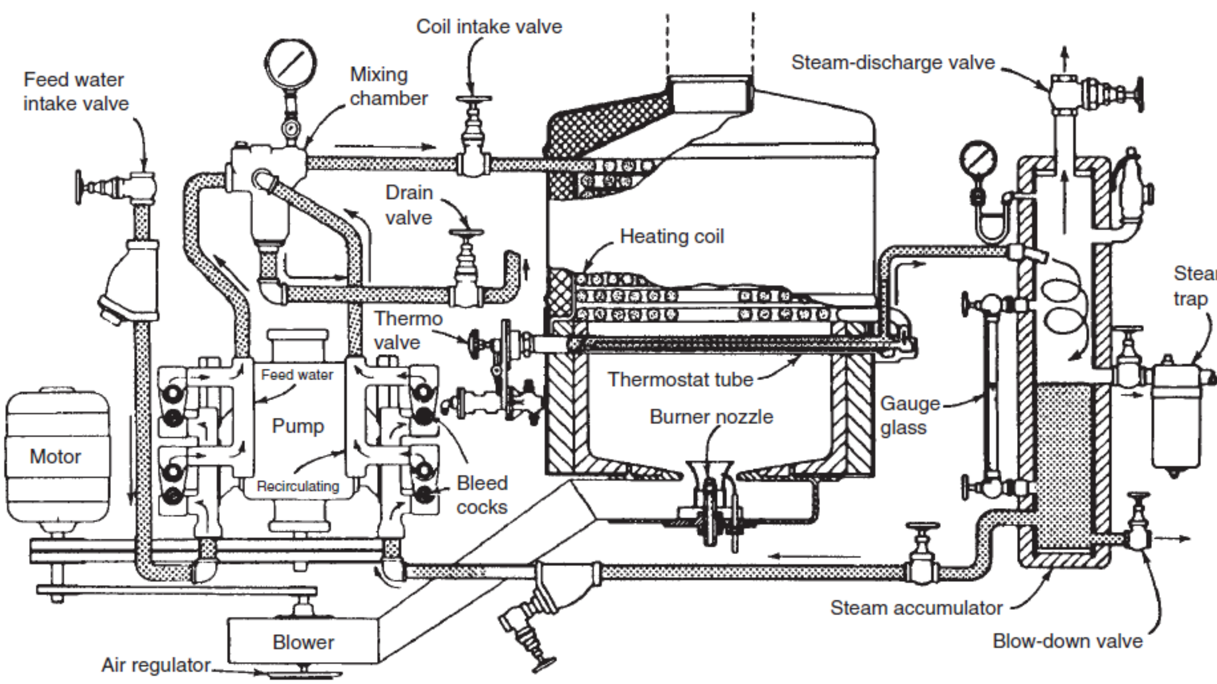

Figure 2. Water-tube steam generator.

Water-tube boilers generally operate with larger capacities and at higher pressures. These systems have greater flexibility and are considered safer to operate than the counterpart fire-tube systems. The safety feature is associated most closely with the change-of-phase occurring within small tubes in a water-tube system rather than in a large vessel in a fire-tube system. The latter system does have an advantage when the load on the system varies considerably with time. Nearly all modern installations in the food industry are of the water-tube design.

One of the more recent developments is the utilization of alternate fuels as a source of energy for steam generation. In particular, combustible waste materials from processing operations have become a viable alternative. In many situations, these materials are available in large quantities and may present a disposal problem.

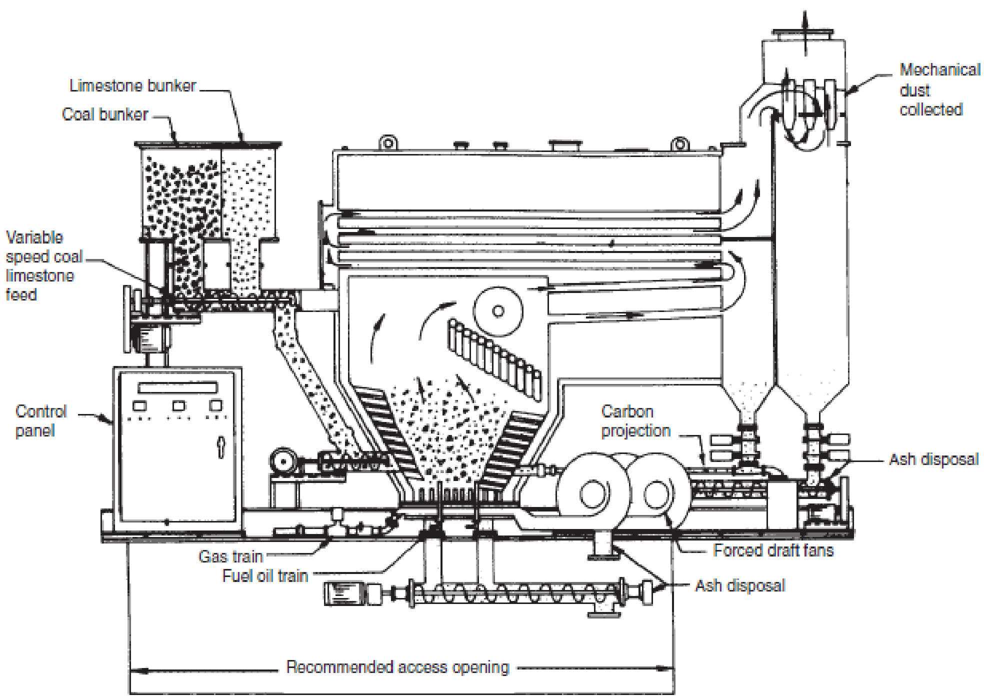

Figure 3. Steam generation system.

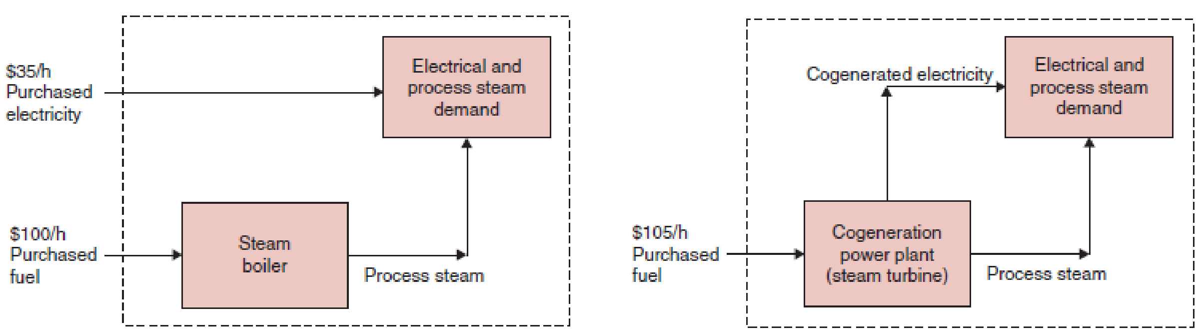

Figure 4. Steam generation systems with and without cogeneration.

Steam generation systems do require modifications in design to accommodate different combustion processes, as illustrated in Figure 3. The advantage of these systems is the opportunity to establish cogeneration, as sketched in Figure 4. This arrangement utilizes steam generated by burning waste materials to generate electric power, as well as to provide steam for processing operations. Depending on the availability of waste materials, significant percentages of electric power demand can be met in this way.

1.2. Thermodynamics of Phase Change

The conversion of water from a liquid to vapor state can be described in terms of thermodynamic relationships. If the phase change for water is presented as a pressure–enthalpy relationship, it appears as shown in Figure 5. The bell-shaped curve represents the pressure, temperature, and enthalpy relationships of water at its different states.

The left-side curve is the saturated liquid curve, whereas the right-side curve is the saturated vapor curve. Inside the bell-shaped curve any location indicates a mixture of liquid and vapor. The region to the right side of the saturated vapor curve indicates superheated vapors.
And the region to the left side of the saturated liquid curve indicates subcooled liquid. At atmospheric pressure, the addition of sensible heat increases the heat content of liquid water until it reaches the saturated liquid curve.

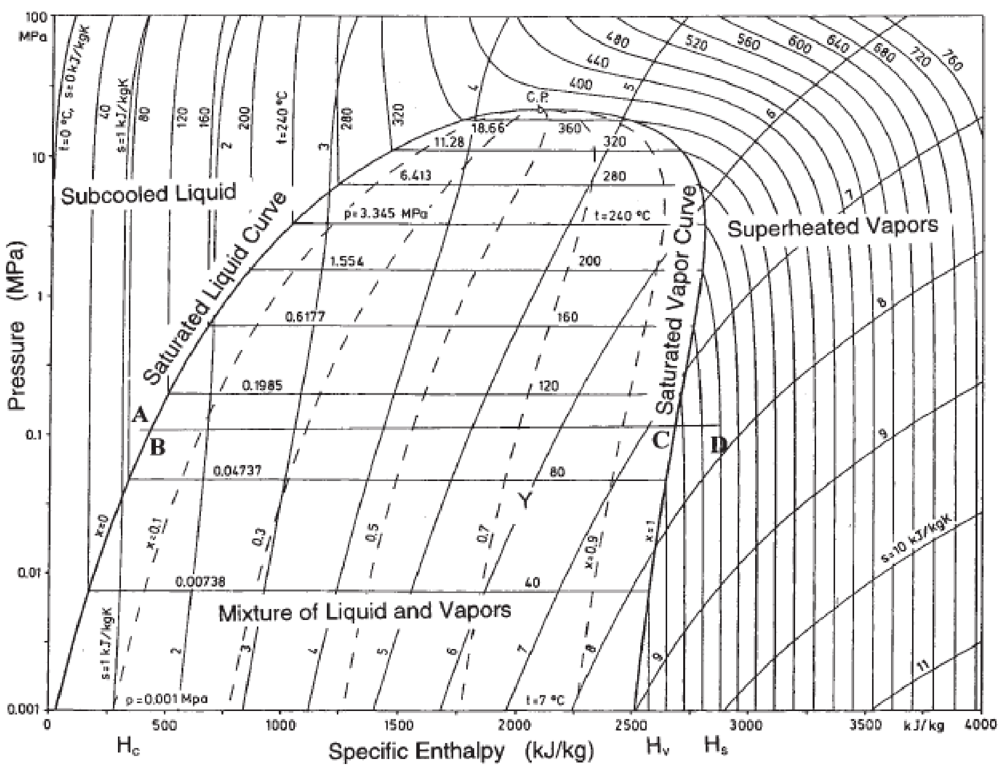

Figure 5. Pressure–enthalpy diagram for steam–water and vapor.

As an illustration, consider a process ABCD on Figure 5. Point A represents water at 90°C and 0.1 MPa pressure. The enthalpy content is about 375 kJ/kg of water. As heat is added to the water, the temperature increases to 100°C at point B on the saturated liquid curve. The enthalpy content of saturated water at point B is H_c (referring to enthalpy of condensate), which can be read off the chart as 420 kJ/kg. Further addition of thermal energy (in the form of latent heat) causes a phase change. As additional heat is added, more liquid water changes to vapor state. At point C, all the water has changed into vapors, thus producing saturated steam at 100°C. The enthalpy of saturated steam at point C is H_v (referring to enthalpy of saturated vapors) or 2675 kJ/kg. Further addition of thermal energy results in superheated steam at the same pressure but higher temperatures.

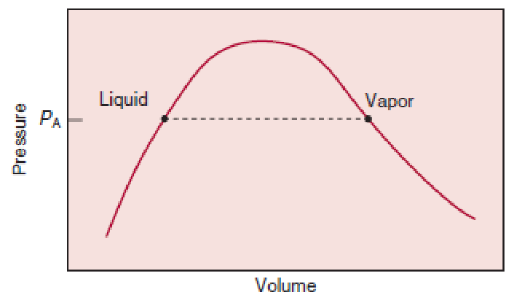

Figure 6. Pressure–volume relationships for water liquid and vapor during phase change.

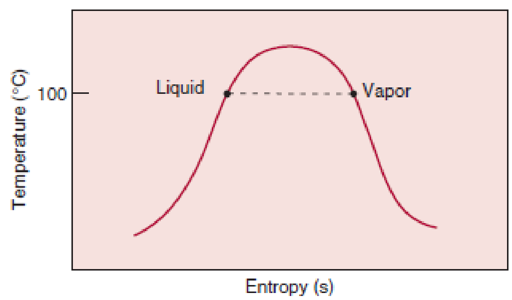

Figure 7. Temperature–entropy relationships for water liquid and vapor during phase change.

Point D represents superheated steam at 200°C with an enthalpy content H_s (referring to superheated steam) of 2850 kJ/kg. Although Figure 5 provides a conceptual understanding of the steam generation processes, steam tables (to be described in the following section) give more accurate values.

By plotting the water phase-change process on pressure–volume coordinates, Figure 6 is obtained. This illustrates that a significant increase in volume occurs during the conversion of water from a liquid to vapor state. In practice, this conversion occurs within a constant volume vessel, resulting in an increase in pressure as a result of the phase-change process. In a continuous steam generation process, the pressure and corresponding temperature of the steam to be used for processing operations are established by the magnitude of thermal energy added from the fuel source.

The third thermodynamic relationship would be on temperature– entropy coordinates, as illustrated in Figure 7. This relationship indicates that the phase change from liquid to vapor is accompanied by an increase in entropy. Although this thermodynamic property has less practical use than enthalpy, it has interesting characteristics. For example, the pressure decrease resulting in a temperature decrease (referred to as "flash cooling ") is, ideally, an isoentropic or constant entropy process. In a similar manner, the compression of steam from a low to a high pressure is a constant entropy process with a corresponding increase in temperature.

There are numerous terms unique to the subject of steam generation. *Saturated liquid* is the condition when **water** is at equilibrium with its vapor. This condition exists at any pressure and corresponding temperature when the liquid is at the boiling point. *Saturated vapor* is **steam** at equilibrium with liquid water. Likewise, the condition exists at any pressure and temperature at the boiling point. *Superheated vapor* is steam at any pressure and temperature when the heat content is greater than saturated vapor. A continuous range of states exists between that of a saturated liquid and that of a saturated vapor, in which the proportions of liquid and vapor vary according to the degree of phase change transition. The extent to which the phase change has progressed is defined as *steam quality*. Normally, steam quality is expressed as a percentage indicating the heat content of the vapor–liquid mixture. In Figure 5, point Y indicates a mixture of liquid and vapor. The steam quality of the mixture represented by this point is 0.7 or 70%, meaning 70% of the mixture is vapor and the remaining 30% is in a liquid state. The enthalpy of steam with a steam quality less than 100% is expressed by the following equation:

$$H = H_c + x_s(H_v - H_c) \qquad \text{----- (Eq. 1)}$$

The preceding equation may be rearranged into the following alternative form:

$$H = (1 - x_s)H_c + x_s H_v \qquad \text{----- (Eq. 2)}$$

The specific volume of steam with a steam quality of x_s can be expressed by

$$V' = (1 - x_s)V'_c + x_s V'_v \qquad \text{----- (Eq. 3)}$$

1.3. Steam Tables

In the previous section, we saw the use of diagrams to obtain thermodynamic properties of steam. A more accurate procedure to obtain these values is by using tables (see Tables A.4.2 and A.4.3). Table A.4.2 presents the properties of saturated steam. The properties include specific volume, enthalpy, and entropy, all presented as a function of temperature and pressure. Each property is described in terms of a magnitude for saturated liquid, an additional value for saturated vapor, and a value representing the difference between vapor and liquid. For example, the latent heat of vaporization, as given in Table A.4.2, is the difference between the enthalpy of saturated vapor and saturated liquid.

Table A.4.2 Properties of Saturated Steam

Temperature (°C)	Vapor pressure (kPa)	Specific volume (m^3/kg)		Enthalpy (kJ/kg)		Entropy (kJ/[kg °C])	
		Liquid	Saturated vapor	Liquid (H_c)	Saturated vapor (H_v)	Liquid	Saturated vapor
0.01	0.6113	0.0010002	206.136	0.00	2501.4	0.0000	9.1562
3	0.7577	0.0010001	168.132	12.57	2506.9	0.0457	9.0773
6	0.9349	0.0010001	137.734	25.20	2512.4	0.0912	9.0003
9	1.1477	0.0010003	113.386	37.80	2517.9	0.1362	8.9253
12	1.4022	0.0010005	93.784	50.41	2523.4	0.1806	8.8524
15	1.7051	0.0010009	77.926	62.99	2528.9	0.2245	8.7814
18	2.0640	0.0010014	65.038	75.58	2534.4	0.2679	8.7123
21	2.487	0.0010020	54.514	88.14	2539.9	0.3109	8.6450
24	2.985	0.0010027	45.883	100.70	2545.4	0.3534	8.5794
27	3.567	0.0010035	38.774	113.25	2550.8	0.3954	8.5156
30	4.246	0.0010043	32.894	125.79	2556.3	0.4369	8.4533
33	5.034	0.0010053	28.011	138.33	2561.7	0.4781	8.3927
36	5.947	0.0010063	23.940	150.86	2567.1	0.5188	8.3336
40	7.384	0.0010078	19.523	167.57	2574.3	0.5725	8.2570
45	9.593	0.0010099	15.258	188.45	2583.2	0.6387	8.1648
50	12.349	0.0010121	12.032	209.33	2592.1	0.7038	8.0763

(Continued)

Table A.4.2 *(Continued)*

Temperature (°C)	Vapor pressure (kPa)	Specific volume (m^3/kg)		Enthalpy (kJ/kg)		Entropy (kJ/[kg °C])	
		Liquid	Saturated vapor	Liquid (H_c)	Saturated vapor (H_v)	Liquid	Saturated vapor
55	15.758	0.0010146	9.568	230.23	2600.9	0.7679	7.9913
60	19.940	0.0010172	7.671	251.13	2609.6	0.8312	7.9096
65	25.03	0.0010199	6.197	272.06	2618.3	0.8935	7.8310
70	31.19	0.0010228	5.042	292.98	2626.8	0.9549	7.7553
75	38.58	0.0010259	4.131	313.93	2635.3	1.0155	7.6824
80	47.39	0.0010291	3.407	334.91	2643.7	1.0753	7.6122
85	57.83	0.0010325	2.828	355.90	2651.9	1.1343	7.5445
90	70.14	0.0010360	2.361	376.92	2660.1	1.1925	7.4791
95	84.55	0.0010397	1.9819	397.96	2668.1	1.2500	7.4159
100	101.35	0.0010435	1.6729	419.04	2676.1	1.3069	7.3549
105	120.82	0.0010475	1.4194	440.15	2683.8	1.3630	7.2958
110	143.27	0.0010516	1.2102	461.30	2691.5	1.4185	7.2387
115	169.06	0.0010559	1.0366	482.48	2699.0	1.4734	7.1833
120	198.53	0.0010603	0.8919	503.71	2706.3	1.5276	7.1296
125	232.1	0.0010649	0.7706	524.99	2713.5	1.5813	7.0775
130	270.1	0.0010697	0.6685	546.31	2720.5	1.6344	7.0269
135	313.0	0.0010746	0.5822	567.69	2727.3	1.6870	6.9777
140	361.3	0.0010797	0.5089	589.13	2733.9	1.7391	6.9299
145	415.4	0.0010850	0.4463	610.63	2740.3	1.7907	6.8833
150	475.8	0.0010905	0.3928	632.20	2746.5	1.8418	6.8379
155	543.1	0.0010961	0.3468	653.84	2752.4	1.8925	6.7935
160	617.8	0.0011020	0.3071	675.55	2758.1	1.9427	6.7502
165	700.5	0.0011080	0.2727	697.34	2763.5	1.9925	6.7078
170	791.7	0.0011143	0.2428	719.21	2768.7	2.0419	6.6663
175	892.0	0.0011207	0.2168	741.17	2773.6	2.0909	6.6256
180	1002.1	0.0011274	0.19405	763.22	2778.2	2.1396	6.5857

Table A.4.3 Properties of Superheated Steam

Absolute pressure (kPa, with sat. temperature, °C)[a]		Temperature (°C)							
		100	150	200	250	300	360	420	500
10	V	17.196	19.512	21.825	24.136	26.445	29.216	31.986	35.679
(45.81)	H	2687.5	2783.0	2879.5	2977.3	3076.5	3197.6	3320.9	3489.1
	s	8.4479	8.6882	8.9038	9.1002	9.2813	9.4821	9.6682	9.8978
50	V	3.418	3.889	4.356	4.820	5.284	5.839	6.394	7.134
(81.33)	H	2682.5	2780.1	2877.7	2976.0	3075.5	3196.8	3320.4	3488.7
	s	7.6947	7.9401	8.1580	8.3556	8.5373	8.7385	8.9249	9.1546
75	V	2.270	2.587	2.900	3.211	3.520	3.891	4.262	4.755
(91.78)	H	2679.4	2778.2	2876.5	2975.2	3074.9	3196.4	3320.0	3488.4
	s	7.5009	7.7496	7.9690	8.1673	8.3493	8.5508	8.7374	8.9672
100	V	1.6958	1.9364	2.172	2.406	2.639	2.917	3.195	3.565
(99.63)	H	2676.2	2776.4	2875.3	2974.3	3074.3	3195.9	3319.6	3488.1
	s	7.3614	7.6134	7.8343	8.0333	8.2158	8.4175	8.6042	8.8342
150	V		1.2853	1.4443	1.6012	1.7570	1.9432	2.129	2.376
(111.37)	H		2772.6	2872.9	2972.7	3073.1	3195.0	3318.9	3487.6
	s		7.4193	7.6433	7.8438	8.0720	8.2293	8.4163	8.6466
400	V		0.4708	0.5342	0.5951	0.6458	0.7257	0.7960	0.8893
(143.63)	H		2752.8	2860.5	2964.2	3066.8	3190.3	3315.3	3484.9
	s		6.9299	7.1706	7.3789	7.5662	7.7712	7.9598	8.1913
700	V			0.2999	0.3363	0.3714	0.4126	0.4533	0.5070
(164.97)	H			2844.8	2953.6	3059.1	3184.7	3310.9	3481.7
	s			6.8865	7.1053	7.2979	7.5063	7.6968	7.9299
1000	V			0.2060	0.2327	0.2579	0.2873	0.3162	0.3541
(179.91)	H			2827.9	2942.6	3051.2	3178.9	3306.5	3478.5
	s			6.6940	6.9247	7.1229	7.3349	7.5275	7.7622
1500	V			0.13248	0.15195	0.16966	0.18988	0.2095	0.2352
(198.32)	H			2796.8	2923.3	3037.6	3.1692	3299.1	3473.1
	s			6.4546	6.7090	6.9179	7.1363	7.3323	7.5698
2000	V				0.11144	0.12547	0.14113	0.15616	0.17568
(212.42)	H				2902.5	3023.5	3159.3	3291.6	3467.6
	s				6.5453	6.7664	6.9917	7.1915	7.4317

The properties of superheated steam are presented in Table A.4.3. The specific volume, enthalpy, and entropy are presented at several temperatures above saturation at each pressure. The property values represent the influence of temperature on the magnitude of specific volume, enthalpy, and entropy.

Another procedure to obtain thermodynamic properties of steam is with the use of mathematical equations. These mathematical equations are available in literature. When programmed into a computer, these equations allow determination of enthalpy values.

1.4. Steam Utilization

The capacity of the steam generation system in a food processing plant is established by requirements of the individual operations using steam. The requirements are expressed in two ways: (1) the temperature of steam needed as a heating medium, and (2) the quantity of steam required to supply the demands of the operation. Since the temperature requirement is a function of pressure, this establishes one of the operating conditions of the system. In addition, the steam properties are a function of pressure (and temperature), which in turn influences the quantity of steam utilized.

The steps involved in determining the capacity of a steam generation system include the following. The thermal energy requirements of all operations utilizing steam from a given system are determined. In most situations, those requirements will establish maximum temperature required and therefore the pressure at which the steam generation system must operate. After the operating pressure of the system is established, the properties of steam are known and the thermal energy available from each unit of steam can be determined. This information can then be used to compute quantities of steam required for the process. An important consideration in sizing the pipe connecting the process to the steam generation system is the volume of steam required. Using the quantity of steam required as expressed in mass units, and the specific volume of the steam being used, the volumetric flow rate for steam leading to the process is computed.

The use of steam by various processes in a food processing plant requires a transport system. The steam generation system is connected by a network of pipelines to the processes using steam. The transport system must account for two factors: (1) the resistance to flow of steam to the various locations, and (2) the loss of thermal energy or heat content during transport.

The flow of steam through a processing plant pipeline can be described by factors in the mechanical energy balance equation, Equation (4).

$$\frac{P_2}{\rho_2} + \frac{1}{2}\bar{u}_2^2 + gz_2 + E_f = \frac{P_1}{\rho_1} + \frac{1}{2}\bar{u}_1^2 + gz_1 + E_P \qquad \text{----- (Eq. 4)}$$

In many situations, the steam generation system and the process using the steam will not be at the same elevation, and the third term on each side of the equation must be considered. Since the steam velocity within the steam generation system will be essentially zero, the kinetic energy term on the left side of the equation will be zero, at least in comparison to the same term on the right side of the equation. The pressure terms in Equation (4) are very important, since the left side represents the pressure at the steam generation system and the right side will be the pressure at the point of use. Since no work E_P is being done on the steam during transport, this term is zero; but the energy loss due to friction will be very important. In many situations, the energy loss due to friction can be translated directly into the loss of pressure between the steam generation system and the point of steam use.

2. FUEL UTILIZATION

The energy requirements for food processing are met in a variety of ways. In general, the traditional energy sources are utilized to generate steam as well as to provide for other utilities used in the processing plant. As illustrated in Table 1, the energy types include natural gas, electricity, petroleum products, and coal. Although the information presented was collected in 1973 and percentages of natural gas utilization have declined somewhat, it seems evident that food processing has a definite dependence on petroleum products and natural gas.

To release the energy available from natural gas and petroleum products, they are exposed to a combustion process. This is a rapid chemical reaction involving fuel components and oxygen. The primary fuel components involved in the reaction include carbon, hydrogen, and sulfur, with the last being an undesirable component. The oxygen for the reaction is provided by air, which must be mixed with fuel in the most efficient manner.

Table1 Energy Use by Fuel Type for 14 Leading Energy-Using Food and Kindred Products Industries

Energy use by type of fuel (%)						
Industry	**Natural Gas**	**Purchased Electricity**	**Petroleum Products**	**Coal**	**Other**	**Total**
Meat packing	46	31	14	9	0	100
Prepared animal feeds	52	38	10	<1	0	100
Wet corn milling	43	14	7	36	0	100
Fluid milk	33	47	17	3	0	100
Beet sugar processing	65	1	5	25	4	100
Malt beverages	38	37	18	7	0	100
Bread and related products	34	28	38	0	0	100
Frozen fruits and vegetables	41	50	5	4	0	100
Soybean oil mills	47	28	9	16	0	100
Canned fruits and vegetables	66	16	15	3	0	100
Cane sugar refining	66	1	33	0	0	100
Sausage and other meat	46	38	15	1	0	100
Animal and marine fats and oils	65	17	17	1	0	100
Manufactured ice	12	85	3	0	0	100

Source: Unger (1975)

3. ELECTRIC POWER UTILIZATION

Electric power has become so commonplace in the food industry that modern plants could not operate without this power source. In fact, most plants of significant size have acquired "back-up" electrical power generators to use in case disruptions occur in the primary supply. It is quite evident that electric power represents the most versatile and flexible power source available. In addition, the cost of electric power is very attractive when compared with other sources. In Figure 8, a tomato processing line is shown along with energy requirements to operate each unit. As seen in this figure, most of the process equipment requires electrical energy for their operation.

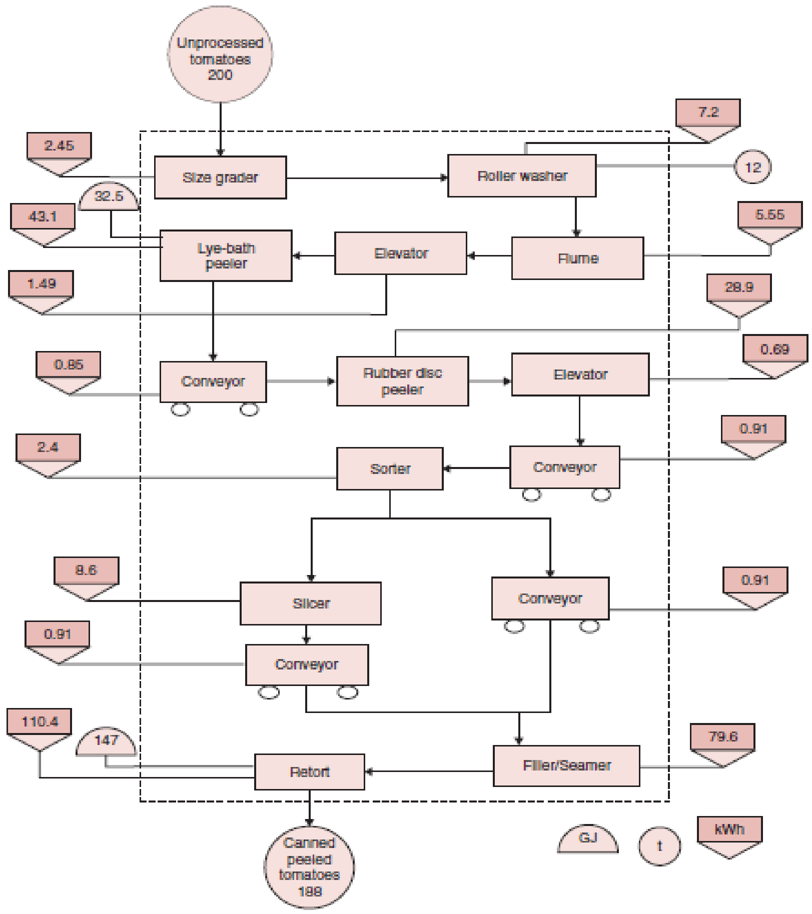

Figure 8. Energy accounting diagram of peeled tomato canning based on an 8-hour shift.

3.1. Electrical Terms and Units

As in most physical systems, electricity has its own set of terms and units. These terms and units are entirely different from most physical systems, and it requires careful analysis to relate the terms to applications. This presentation is elementary and is intended to be a brief introduction to the subject. The following terms are essential.

- **Electricity** can be defined as the flow of electrons from atom to atom in an electrical conductor. Most materials can be considered conductors, but will vary in the ability to conduct electricity.
- **Ampere** is the unit used to describe the magnitude of electrical current flowing in a conductor. By definition, 1 ampere (A) is 6.06 $\times 10^{18}$ electrons flowing past a given point per second.
- **Voltage** is defined as the force causing current flow in an electrical circuit. The unit of voltage is the volt (V).
- **Resistance** is the term used to describe the degree to which a conductor resists current flow. The ohm (Ω) is the unit of electrical resistance.

- **Direct current** is the type of electrical current flow in a simple electrical circuit. By convention, current is considered to flow from a positive to a negative terminal of a voltage generator.
- **Alternating current** describes the type of voltage generated by an AC (alternating current) generator. Measurement of the actual voltage generated would indicate that the magnitude varies with time and a uniform frequency. The voltage ranges from positive to negative values of equal magnitudes. Most electrical service in the United States operates at 60 cycles per second (60 Hz).
- **Single-phase** is the type of electrical current generated by a single set of windings in a generator designed to convert mechanical power to electrical voltage. The rotor in the generator is a magnet that produces magnetic lines as it rotates. These magnetic lines produce a voltage in the iron frame (stator) that holds the windings. The voltage produced becomes the source of alternating current.
- **Three-phase** is the type of electrical current generated by a stator with three sets of windings. Since three AC voltages are generated simultaneously, the voltage can be relatively constant. This type of system has several advantages compared with single-phase electricity.
- **Watt** is the unit used to express electrical power or the rate of work. In a direct current (DC) system, power is the product of voltage and current, whereas computation of power from an alternating current (AC) system requires use of a power factor.
- **Power factors** are ratios of actual power to apparent power from an alternating current system. These factors should be as large as possible to ensure that excessive current is not carried through motors and conductors to achieve power ratings.
- **Conductors** are materials used to transmit electrical energy from source to use. Ratings of conductors are on the basis of resistance to electrical flow.

3.4 Electric Motors

The basic component of an electric energy utilization system is the electric motor. This component converts electrical energy into mechanical energy to be used in operation of processing systems with moving parts.

The majority of the motors used in food processing operations operate with alternating current (AC), and their operation depends on three basic electrical principles. These principles include the electromagnet, formed by winding insulated wire around a soft iron core. Current flow through the wire produces a magnetic field in the iron core; orientation of the field is dependent on the direction of current flow.

The second electrical principle involved in the operation of a motor is electromagnetic induction. This phenomenon occurs when an electric current is induced in a circuit as it moves through a magnetic force field. The induced electric current produces a voltage within the circuit, with magnitude that is a function of the strength of the magnetic field, the speed at which the current moves through the field, and the number of conductor circuits in the magnetic field.

The third electrical principle is alternating current. As indicated earlier, this term refers to a current that changes direction of flow in a consistent manner. Normal electric service is of 60 Hz, indicating that the change in current flow direction occurs 60 times per second.

An electric motor contains a stator: a housing that has two iron cores wound with insulated copper wire. The two cores or windings are located opposite one another, as illustrated in Figure 9, and the leads from the windings are connected to a 60 Hz alternating current source. With this arrangement, the stator becomes an electromagnet with reversing polarity as the current alternates.

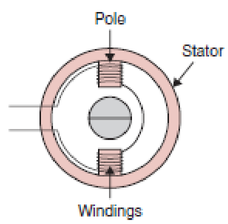

Figure 9. Schematic diagram of a stator.

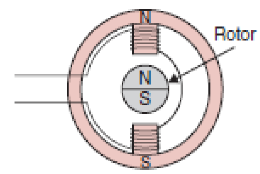

Figure 10. Schematic diagram of a stator with rotor.

A second component of an electric motor is the rotor: a rotating drum of iron with copper bars. The rotor is placed between the two poles or windings of the stator (Fig. 10). The current flow to the stator and the resulting electromagnetic field produces current flow within the copper bars of the rotor. The current flow within the rotor creates magnetic poles, which in turn react with the magnetic field of the stator to cause rotation of the rotor. Due to the 60 Hz alternating current to the stator, the rotation of the rotor should be 3600 revolutions per minute (rpm), but it typically operates at 3450 rpm.

Although there are numerous types of electric motors, they operate on these same basic principles. The most popular motor in the food processing plant is the single-phase, alternating current motor. There are different types of single-phase motors; the differences are related primarily to the starting of the motor.

The selection of the proper motor for a given application is of importance when ensuring that efficient conversion of electrical to mechanical energy occurs. The selection process takes into account the type of power supply available, as well as the use of the motor. The type and size of load must be considered, along with the environmental conditions of operation and the available space.

3.6 Electric Lighting

Another primary use of electric power in food processing plants is to provide illumination of work spaces. Often the work productivity of workers within the plant will be dependent on the availability of proper lighting. The design of a lighting system for a workspace will depend on several factors. The light must be distributed properly within the space, and the light source must be of sufficient size and efficiency. The light source must be supported properly and easily replaced or serviced. Finally, the cost of the entire system will be a factor to consider.

Light can be defined as visually evaluated radiant energy. Light is a small portion of the electromagnetic spectrum and varies in color depending on the wavelength. The intensity of a light at a point location is measured in the unit *lux*: the magnitude of illumination at a distance of one meter from a standard candle. A light source can be expressed in lumens: the amount of light on one square meter of surface when the intensity is one lux.

Two types of light sources are used in food processing plants: the incandescent lamp and the fluorescent lamp. The incandescent lamp uses a tungsten filament through which current flows. Due to the high electrical resistance of the filament, the flow of current through it causes it to glow white-hot. These types of lamps will provide efficiencies of approximately 20 lumens per watt.

A fluorescent lamp uses an inductance coil to create a current discharge within the tube. The heat from the discharge causes electrons to be removed from mercury vapor within the tube. The return of the electrons to the shell of mercury vapor causes emission of ultraviolet rays. These rays react with phosphor crystals at the tube surface to produce light. Fluorescent lamps are two to three times more efficient than comparable incandescent lamps. Although there are other factors to consider when comparing incandescent and fluorescent lamps, the efficiency and the longer life of fluorescent lamps are the most important.

One of the basic decisions related to lighting system design is determining the number of light sources required to maintain a desired level of illumination. An expression for illumination can be

$$\text{Illumination} = \frac{(\text{lumens/lamp}) \times \text{CU} \times \text{LLF}}{\text{area/lamp}} \qquad \text{------Eq. 5}$$

where CU is the coefficient of utilization and LLF is the light loss factor.

The preceding equation indicates that the illumination maintained in a given space is a function of the magnitude of the light source and the number of lamps in the space. The coefficient of utilization CU accounts for various factors within the space, such as room size proportions, location of lamps, and workspace light. Light loss factors LLF account for room surface dust, lamp dust, and lamp lumen depreciation.

Problem: A work area within a food processing plant is to be maintained at a light intensity of 800 lux. The room is 10 by 25 m, and 500-watt incandescent lamps (10,600 lumens/lamp) are to be utilized. A CU of 0.6 and LLF of 0.8 have been established. Determine the number of lamps required.

Given

Desired light intensity = 800 lux

Room size = 10 m by 25 m = 250 m^2

Lamps are 500 W, or 10,600 lumens/lamp

Coefficient of utilization CU = 0.6

Light loss factor LLF = 0.8

Approach

Equation (5) can be used to determine area/lamp, and the result is combined with the given room area to calculate the number of lamps required.

Solution

1. Equation (5) can be used to compute the area per lamp allowed for the desired illumination.

$$Area/lamp = \frac{10{,}600 \times 0.6 \times 0.8}{800} = 6.36\, m^2$$

2. Based on the preceding,

$$Number\ of\ lamps = \frac{10 \times 25}{6.36} = 39.3 \quad or \quad 40.$$