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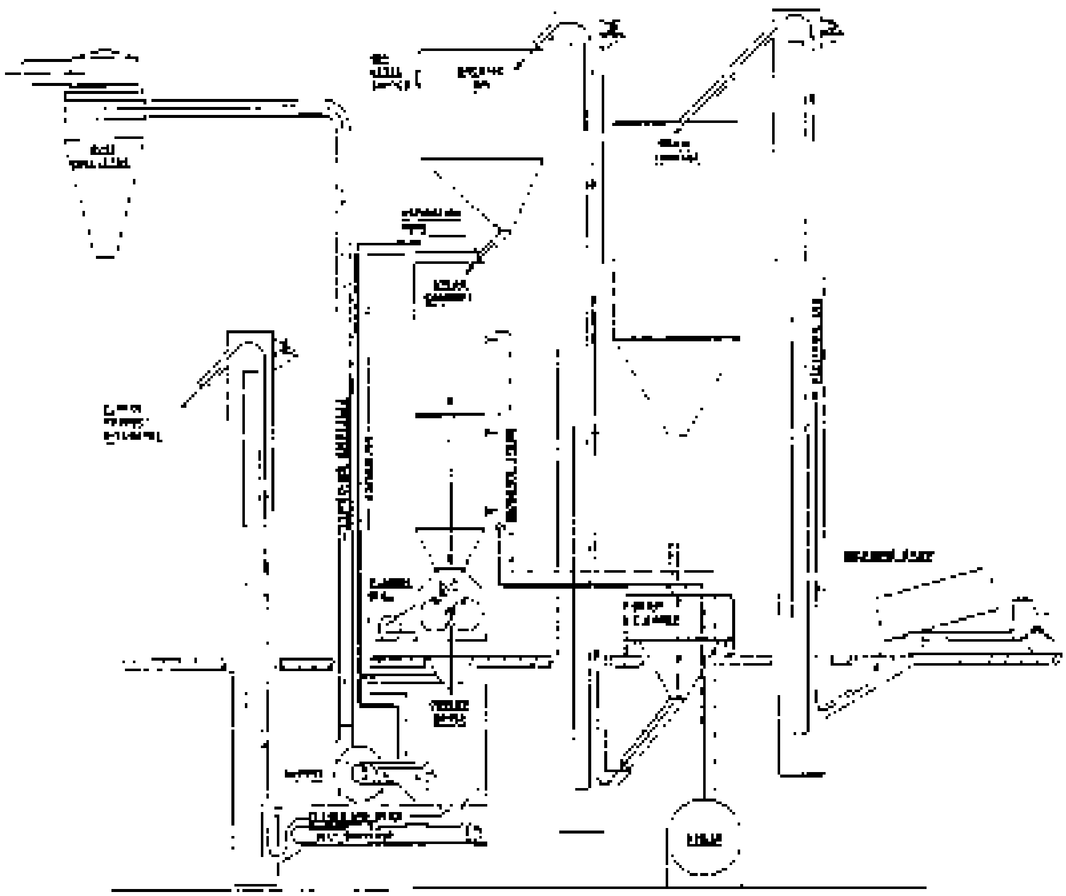
Steam Flaking – Focus on Conditioning



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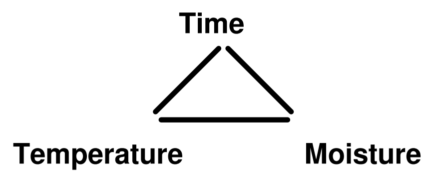
Steam Flaking – Focus on Conditioning

Steam flaking of cereal grains such as corn, barley, sorghum, and wheat for beef cattle improves feed conversion and animal growth. Steam flaking also improves starch digestion and lactation performance in dairy cows. In many locations around the country but especially in the Southwest and on the West coast, feed lots and feed mills supplying dairies are seeing the benefits of consolidating several smaller flaking units into one, two, or three larger machines. The advantages of fewer larger machines include reduced maintenance and operating costs, more efficient utilization of existing space, and increased capacity and product quality.

Conditioning for steam flaking requires time, temperature, and moisture. Ordinarily the temperature and moisture are provided by steam, and the time is provided by a relatively large vessel commonly referred to as a steam chamber, steam chest, or steamer. As the capacity of steam flaking systems increase, the size of the conditioners must increase to provide adequate retention time for the temperature and moisture to fully penetrate each kernel of grain.

Steam Flaking Systems - Conditioning

- **Conditioning Requires TTM**



While years ago retention times of 12 to 15 minutes were considered adequate, many of today's processors are employing steam chambers sized to produce retention times of 60 minutes or more. As the capacity of some steam flaking lines approach 30 tons per hour, the size of the steam chambers become remarkably large!

Steam Flaking Systems - Conditioning

Steam Conditioning

1) Increase Moisture
Normally 10% Maximum Moisture Added
18% miminum for good gelatinization

2) Increase Temperature
Normally 212° F (100°C) Maximum

Retention Time Varies
Material(s) Being Processed
Flake Thickness Desired

One approach to reduce the size of the steam chamber required without sacrificing conditioning has been to apply water with a surfactant or wetting agent to the grain prior to introducing the grain to the steam chamber. Ordinarily the grain will be allowed to "temper" for 1 to 24 hours prior to steaming and flaking. This temper time permits the moisture to penetrate each kernel and hopefully reach equilibrium before the grain is admitted to the steam chamber. The higher moisture (and action of the surfactant) improves the ability of the grain to take up moisture as well as increasing the thermal conductivity of the kernel of grain. One disadvantage of tempering is the higher moisture grain will require more BTU's per pound to raise the temperature since water has a higher specific heat that the grain. The specific heat of water is 1 (requires 1 BTU to raise 1 pound of water 1° F) and the specific heat of the dry matter in grain is .31 (1 BTU will increase the temperature of one pound of grain more than 3° F).

Figure 1 below describes initial and final moisture level of grain heated from 60° F to 212° F assuming 100% steam quality and 100% efficiency of the steam chamber. Note that under these "perfect" conditions that the grain would have to enter the steam chamber at 14% moisture in order to attain the minimum moisture level required for efficient gelatinization of the starch (18%). For atmospheric steam chambers (vessels not designed to operate under pressure) the highest temperature possible is approximately 212° F. Of course the actual temperature obtained in the steam chamber may vary somewhat due to elevation and local conditions, 212° F is the normal target temperature for steam conditioning in most steam flaking operations

FIGURE 1

Steam Flaking / Grain Moisture / Specific Heat
100% Steam Quality and 100% Steam Chamber Efficiency
All Figures and Calculations on "Per Ton" Basis

Moisture In	Specific Heat	Temperature In	Temperature Out	BTU Req	# Steam @ 60 PSI	Final Moisture
10%	0.3790	60	212	115,216	97.5	14.2%
11%	0.3859	60	212	117,314	99.3	15.2%
12%	0.3928	60	212	119,411	101.0	16.2%
13%	0.3997	60	212	121,509	102.8	17.3%
14%	0.4066	60	212	123,606	104.6	18.3%
15%	0.4135	60	212	125,704	106.3	19.3%
16%	0.4204	60	212	127,802	108.1	20.3%
17%	0.4273	60	212	129,899	109.9	21.3%
18%	0.4342	60	212	131,997	111.7	22.3%
19%	0.4411	60	212	134,094	113.4	23.3%

In actual operation these ideal conditions are never realized. In reality the steam quality may vary between 65 and 95% depending on the design of the steam supply system, the distance from the boiler to the steam chamber, insulation on the steam lines, and many other factors. The use of a pressure regulator in the steam line supplying a steam flaking system tends to improve steam quality (due to the pressure drop across the regulator) in addition to providing a more consistent pressure to the steam chamber. In many cases it may be desirable to have "wet" steam supplied to the steam chamber in order to add extra moisture to the grain being processed. In these cases the use of a steam regulator will be counter productive. Wherever dry grain is processed or where ambient conditions favor drying (low relative humidity) "wet" steam will be preferred for steam flaking operations. When drying conditions are more challenging, as is the case when the relative humidity is more than 50%, better steam quality will reduce the moisture added during conditioning is the steam chamber. Figure 2 details initial and final moisture levels obtained in the steam chamber assuming varying steam qualities and steam chamber efficiencies.

FIGURE 2

Steam Flaking / Grain Moisture / Specific Heat
Assume 85% steam quality @ 60 PSI (1005 BTU/#)

Moisture In	# Steam Added / Steam Chamber Efficiency					
	# Steam	100%	# Steam	80%	# Steam	60%
10%	114.7	14.9%	143.3	16.0%	191.1	17.9%
11%	116.8	15.9%	146.0	17.1%	194.6	18.9%
12%	118.9	16.9%	148.6	18.1%	198.1	19.9%
13%	120.9	18.0%	151.2	19.1%	201.6	21.0%
14%	123.0	19.0%	153.8	20.1%	205.0	22.0%
15%	125.1	20.0%	156.4	21.2%	208.5	23.0%
16%	127.2	21.0%	159.0	22.2%	212.0	24.1%
17%	129.3	22.0%	161.6	23.2%	215.5	25.1%
18%	131.4	23.1%	164.2	24.2%	219.0	26.1%
19%	133.5	24.1%	166.8	25.2%	222.4	27.1%

As can be seen in the following charts, the affects of steam quality and steam chamber efficiency can have a dramatic effect on the moisture level obtained in the corn, even when the temperature is held constant. Based on 14% moisture corn, if the steam is 100% quality and the steam chamber 100% efficient, the final moisture content of the grain will only be about 17.6%.

20,000# @ 14% = 2800 # water initially 2800 + 872 = 3672# water / 20, 872 = 17.6% final moisture content.

In reality, most steam chambers operate at efficiencies less than 100%. Depending on the ambient conditions and the design of the steam chamber, actual operating efficiencies may vary from 60% to around 85% efficient. That means of the steam energy supplied to the grain, only 60% to 85% actually goes into heating the grain, and the rest is lost either directly to the atmosphere (visible steam escaping) or heat lost through radiation to the atmosphere.

Calculating Steam Consumption

100% Quality Steam, 100% Efficiency

Assume: 10 Tons/Hour on Corn
Incoming temperature 60° F
Incoming moisture 14%
Condition to 212° F

10 Ton x 2,000#/Ton x .33 x (212-60) = 1,003,200 BTU Req

Saturated steam @ 212°F and ATM Pressure = 1150 BTU/#

1,000,000 BTU / 1150 BTU/# = 872# Steam Required

872# Steam (Water) / 20,872# Corn = Addition of 4.2% Moisture

Calculating Steam Consumption

80% Quality Steam, 80% Efficiency

Assume: 10 Tons/Hour on Corn
Incoming temperature 60° F
Incoming moisture 14%
Condition to 212° F

10 Ton x 2,000#/Ton x .33 x (212-60) / .8 = 1,254,000 BTU Req

80% Quality steam @ 212°F and ATM Pressure = 956 BTU/#

1,254,000 BTU / 956 BTU/# = 1312# Steam Required

1312# Steam (Water) / 21,312# Corn = Addition of 6.2% Moisture

If the steam quality supplied to the steam chamber is 80%, and the steam chamber is 80% efficient, then in the case of 14% moisture corn introduced at 60° F, the final moisture content will be 19.3%.

2800 + 1312 = 4112# water / 21,312 =
19.3% final moisture content.

If the steam quality is very low (60%) and the steam chamber design does not make good use of the steam or the ambient conditions are poor (room temperature less than 50° F and air movement across the steam chamber) the steam chamber efficiency may be as low as 60%. In this case, even though the 14% incoming corn is conditioned to the same temperature, much more steam (water) is added resulting in a higher finished moisture.

2800 + 2171 = 4971# water / 22,171 =
22.4% final moisture content.

Calculating Steam Consumption

60% Quality Steam, 60% Efficiency

Assume: 10 Tons/Hour on Corn
Incoming temperature 60° F
Incoming moisture 14%
Condition to 212° F

10 Ton x 2,000#/Ton x .33 x (212-60) / .6 = 1,672,000 BTU Req

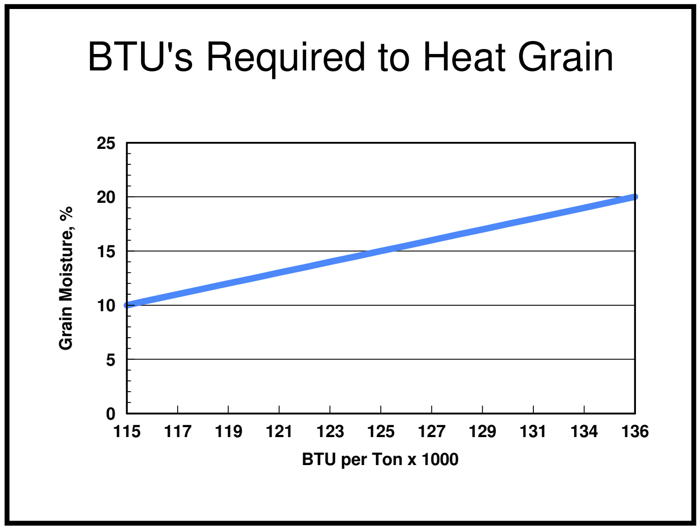
60% Quality steam @ 212°F and ATM Pressure = 770 BTU/#

1,667,000 BTU /770 BTU/# = 2171# Steam Required

2171# Steam (Water) / 22,171# Corn = Addition of 9.7% Moisture

Temper or Pure Steam?

As noted earlier, in some cases customers will add water and surfactants to the grain prior to the steam chamber in order to obtain the desired finished moisture level in the conditioned grain. Unless the temper time is exceptionally long (24-48 hours) the use of water alone will not provide acceptable results as the grain will not take up the moisture. In most cases the addition of moisture ahead of the steam chamber is required only when the steam chamber is too small to provide sufficient time for the moisture and temperature to fully penetrate the kernels of grain. By adding some moisture "up front" the steam chamber may only be required to add 3-4% moisture while increasing the temperature of the grain to 212° F for good flaking results. With a good moisture monitor and automated addition system, presenting a uniform grain moisture to the steam chamber may simplify steam chamber operation, as the steam pressure and operating conditions will always be the same. On the other hand, the energy required for conditioning my actually increase, due to more BTU's required to heat the higher moisture grain. In addition, the chemical surfactants used add to the total cost of the flaking operation.



On average, most chemical additives will cost between $0.32 and $0.40 per ton, based on incoming grain moisture of 14% and a target "tempered grain" moisture of 18-19%. Because of the higher moisture content, the steam used to condition tempered grain must be better quality which translates into higher boiler pressure required. This 'high quality" steam will increase the temperature of the grain with less moisture added, but is more costly to produce (per pound of steam) because more BTU's are required.

Steam Flaking - Conditioning Costs

Assumptions: 100% make up water @ 50° F
Boiler pressure @ 60 PSI (307°F)
Boiler efficiency = 85%
Natural gas @ $0.27 / 100,000 BTU (Therm)

1% moisture addition per ton = 20# steam

$$\frac{20 \times ((307-50) + 970)}{85\%} = 28{,}870 \text{ BTU's required}$$

$$\frac{28{,}870}{100{,}000} \times \$0.27 = \$0.078 \text{ per 1\% moisture addition per ton}$$

Steam Flaking - Conditioning Costs

Assumptions: 100% make up water @ 50° F
Boiler pressure @ 120 PSI (350°F)
Boiler efficiency = 85%
Natural gas @ $0.27 / 100,000 BTU (Therm)

1% moisture addition per ton = 20# steam

$$\frac{20 \times ((350-50) + 970)}{85\%} = 29{,}882 \text{ BTU's required}$$

$$\frac{29{,}882}{100{,}000} \times \$0.27 = \$0.081 \text{ per 1\% moisture addition per ton}$$

The total cost to condition grain with tempering can be determined by adding the various steps together. Assuming 14% moisture grain tempered to 18% moisture before the steam chamber, then conditioned to 212° F in the steam chamber with high quality, high pressure steam, the final moisture will be a minimum of 22.3%. Based on $0.08 per 1% moisture addition ton for the chemical treatment, and $0.081 per ton per 1% moisture addition for steam, the total cost to temper and condition will be (18-14) x $0.08 + (22.3 – 18) x $0.081 = $0.668 per ton for total conditioning costs. These costs exclude the water added in tempering or any maintenance or service charges for the moisture addition system.

Three Types of Steam

	Wet	Saturated	Superheated
Temperature	Saturation 212° F @ Atm	Saturation 212° F @ Atm	> Saturation > 212° F @ Atm
Energy Content	978 BTU/# 212° F 85% Quality	1150 BTU/# 212° F 100% Quality	1384 BTU/# 700° F Superheated
Phase	Liquid & Vapor	Vapor Only	Vapor Only
Condensation	Immediate	Immediate	Must cool first
Temperature Rise per % Moisture Added	24° F	28° F	34° F

Assuming the same 14% moisture corn conditioned with steam only, lower pressure (thus lower cost) steam can be used. In fact, if the steam is too high quality it is possible that the steam / grain mixture will not cool enough in the steam chamber to allow the steam to condense into water, giving up its heat content and contributing the moisture to the grain. Again based on 14% moisture corn introduced to the steam chamber, conditioned to 212° F using 85% quality steam and 60% efficiency of the steam chamber, the grain will exit the steam chamber at 22% final moisture. Conditioning will require 205 #'s of steam and will cost approximately (22-14) x $0.078 = $0.624 per ton total conditioning costs.

The use of chemical grain treatment(s) and tempering prior to steam flaking proposes the following benefits: consistent moisture into the steam chamber, thus consistent steam quality and quantity required
better thermal conductivity of the grain
faster conditioning due to improved heat and moisture transfer within the grain

The cost of conditioning with water / chemical addition and tempering is slightly higher than using steam only. Tempering may be beneficial in situations where the incoming grain moisture varies considerably, when very dry grain must be processed (<13% incoming moisture), or when the steam chamber is not large enough to provide adequate conditioning time. Keep in mind in the examples noted here no effort was made to calculate the cost of operating and maintaining the moisture addition systems, or the cost of water added in the tempering process. The cost of water should be the same whether it is added directly in tempering, or as steam.

When the steam chamber is adequately sized and it is possible to adjust the steam quality as required, conditioning with steam alone does seem to be the low cost solution. To effectively control the conditioning operation, it may be necessary to check the grain moisture periodically and increase or decrease the steam supply pressure (adjust steam quality) to suit the current operating conditions. As long as the steam chamber is large enough to provide a retention time of 45 to 60 minutes (depending on the type of flakes to be produced) conditioning with steam alone can provide the same results as systems including a tempering stage.