To Store or Not to Store?

Biomass Boiler Plant Performance and Thermal Storage, Buffer Tanks and Heat Dump Tanks

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Introduction:

The guidance summarized here is based upon the monitoring of scores of boiler plants over hundreds of thousands of boiler-hours of operation in real-world conditions. In putting this together, we are hoping to point out what we feel to be some of the most important issues to consider relating to biomass plant design, particularly in regards to storage. We do not provide calculations and formulas, but rather information to consider when performing your calculations.

We focus primarily on automatic, auto-start, modulating biomass pellet/chip boiler plants for small-large educational, commercial and industrial buildings. That being said, much of the information presented here may be valuable when dealing with other types of pellet/chip boilers or other facilities. Storage for cordwood boilers is not discussed here.

The treatment is not comprehensive, and we welcome any suggestions/additions.

Definitions:

<u>Biomass Fuel Fraction</u> (BFF): This is the ratio of the btus consumed by the biomass plant to the number of btus consumed by the entire plant (= biomass + fossil-fuel). A high BFF indicates that fossil fuel has been very effectively displaced by biomass.

<u>Boiler Plant Controls</u>: Generally provided by the manufacturer, these controls adjust the output of a biomass boiler plant of one or more boilers by determining how many boilers to fire and at what modulation rate. Staging control might be built into a boiler manufacturer's control package, or it could be purchased separately from the boiler manufacturer or from a third party. "Boiler plant controls," as used in this document, are not supplied by controls contractors and their BEMS/BAS. In most cases we're familiar with, the extent of biomass boiler plant influence from controls contractors consists of external on/off control of the biomass boiler plant, backup boiler operation, and in some cases control of mixing for outdoor reset control. These are not our primary focus areas in this document.

<u>Buffer Tank</u> (BT): The purpose of a BT is to smooth out minor mismatches between the boiler output and the facility's heat requirements. The idea is to prolong the operation of the boiler, providing greater efficiency and responsiveness to load. Presumably, a BT will also provide the required functionality of a Heat Dump Tank (see below). BTs are generally sized based on the output capacity of boilers. For example, the NYSERDA guideline is to employ 2 gallons of storage for every kbtu/hr of boiler output of the largest boiler in the plant.

<u>Distribution ΔT</u>: This is the temperature drop occurring due to heat being delivered to the building: Distribution Supply Temperature – Distribution Return Temperature. It is not the "ΔT across the tank," which is sometimes referred to. Distribution Supply Temperature is the temperature after any mixing. In most hydronic design, the Distribution ΔT is nominally 20°F. Such a ΔT rarely occurs in practice unless particular measures are put in place to enforce it. Determination of whether your system enforces design ΔT by measuring and adjusting flow is critical. <u>Doing this using a ΔT-controlled circulator is the only way to enforce design ΔT</u>. (Bear in mind that an unbalanced multi-zone distribution system—or even a branched single-zone distribution system—may experience poor heat delivery to some areas if served by a ΔT-controlled circulator.)

Heat Dump Tank (HDT): For lack of better term, a HDT is designed with one purpose only—to provide the boiler plant with a safe place to dump excess heat in the event that the facility no longer needs it. (This need not be an actual tank; it could also be a fan-coil or other dump zone.)

Storage: Storage is a generic term that encompasses all three types of storage defined here: Heat Dump Tank, Buffer Tank and Thermal Storage.

Thermal Storage (TS): TS accomplishes the goal of the BT, but adds the component that it can store a significant and useful amount of heat to be utilized when the boiler plant is off and/or when it encounters a very large load, such as during recovery from setback. Properly sized TS must incorporate the needs of the building; sizing based on boiler output alone will not be adequate. The guidance of 2 gallons storage per kbtu/hr output does NOT apply here.

Assumptions:

Our assumption is that the goal is to design a solidly performing system.

Such a system must, in descending order of importance:

1. Supply heat when needed, and consistently at the temperature required.
2. Meet or exceed all emissions requirements.
3. Operate in such a way to maximize the lifetime of the components. (Short-cycling kills more than just efficiency.)
4. Be serviceable.
5. Be efficient. (This is intentionally the lowest priority since a high-efficiency system that doesn't do the job you need it to do in a safe way is not much use.)

We acknowledge that consistent heat delivery to the distribution system at a desired temperature is not critical in certain installations like high-mass buildings or where large supply temperature swings are acceptable. However, that being said, all systems have the best possibility of delivering the greatest level of comfort if the heating plant can deliver what is asked of it, when it is asked.

So, when considering the options for storage, we don't just consider emissions and efficiency.

NOTE:

We'd like to point out that special focus on storage may be misplaced. Storage is only a solution to the problem when the problem requires storage! The question shouldn't be, "What storage do we need here?" but rather, "How do we make this installation perform well?"

Storage is not a solution for overcoming deficiencies in boiler plant control. In fact, its presence—even in huge quantities—is absolutely no guarantee of good performance. If manufacturer's boiler plant control requires certain characteristics of the distribution system, such as low temperatures and regulated flow, storage will not solve any problems unless that distribution system behavior is guaranteed. In fact, boiler plant control that cannot effectively accommodate the characteristics of the distribution system can easily render the customer's investment in storage a waste of money and leave them uncomfortable as well.

Of course, this does not mean the distribution system must be adjusted to satisfy the assumptions built into the boiler plant controls. The controls can be modified to match the reality of the distribution system.

Some questions to frame the overall system design:

- Do you understand:
    - The boiler and boiler plant control sequence?
    - Design intent of control sequence (what is the overall purpose)?

  This second point is very important. If you or your boiler manufacturer cannot say what they are trying to achieve with their control strategy AND why they are trying to achieve it, then even strict adherence to their design guidelines (*e.g.*, distribution ΔT, flow regulation, tank size, stratification) may lead to poor results.
- Does the proposed boiler plant have built-in controls that assume a low-temperature distribution system with a highly stratified tank? If so, it may not be a good match for the building, regardless of how much storage is used. The risk of not taking the time to understand the design intent and requirements of the manufacturer's (or aftermarket) boiler plant controls is that the boiler plant you design/install may have poor performance.
- Will setback be implemented? (Recovery from setback imposes a load greater than design load every single day. How will that be handled?)
- Is the installation a base-load biomass installation where the biomass boiler(s) are intended to run nearly full-time?
- How important is the BFF? (This impacts sizing of plant and/or TS and may influence the decision of whether to employ setback.)
- How well can the boiler plant under consideration respond to changes in building loads? Does the modulation strategy place a high emphasis on riding out no-load periods by modulating down but remaining on (thereby maximizing the utility of any installed storage)? How rapidly can the boilers achieve full output from a dead stop? The performance of the plant hinges upon this type of responsiveness.
- How consistently can the boilers in the plant run? Do they turn off regularly for cleaning/fueling? If so, for how long are they unavailable? Is there anything preventing all boilers turning off to refuel/clean at the same time? Might those off periods adversely impact recovery from setback, for example? Have you incorporated this information into your storage sizing?
- Are you concerned with emissions problems due to short cycling under part-load conditions? Consider sizing a BT such that you can achieve a minimal boiler run time. Carefully examine your assumptions about what the boiler output will be in these conditions (full output, minimal output, do you know?) and how hot the tank may be safely heated. What is a reasonable estimate for the starting temperature of the tank? Is it stratified?

Poor Performance—What Does That Mean?

We have mentioned the possibility of poor system performance in the paragraphs above, and also refer below in the decision tree to the possibility of certain configurations failing. What does it mean for a system to have poor performance or for a certain strategy to fail?

Return to our definition of a solidly performing system.

Such a system must, in descending order of importance:

1. Supply heat when needed, and consistently at the temperature required.
2. Meet or exceed all emissions requirements.
3. Operate in such a way to maximize the lifetime of the components.
4. Be serviceable.
5. Be efficient.

If the issues we highlight are not carefully handled, system performance may be poor. In particular, in response to each of these points, these poorly performing systems:

1. Will not be able to provide the building with the desired supply temperature in a consistent way. Boilers may respond sluggishly to calls for more heat. They may quickly heat up a BT, and then turn off, becoming unavailable for subsequent loads. This can lead to large swings in supply temperature. A staging strategy may even prevent all boilers from firing when high output and high temperatures are needed. Basically, the boiler plant will not perform its core function—to supply heat at a consistent temperature. Other than the obvious comfort concern, another implication of this situation is that if the biomass boiler plant cannot reliably produce heat for the building, the fossil-fuel backup/peaking boiler will run far more than projected and more than necessary. BFF suffers.
2. Should have satisfactory steady-state emissions, but a strategy that does not put great importance on reducing boiler short cycling will generate unnecessary emissions due to excessive startup/shutdown.
3. Will cause active parts on the boiler to receive unnecessary wear if reducing short cycling is not a priority.
4. Should not affect serviceability.
5. Will exhibit poor real-world efficiency, particularly if short cycling is not addressed.

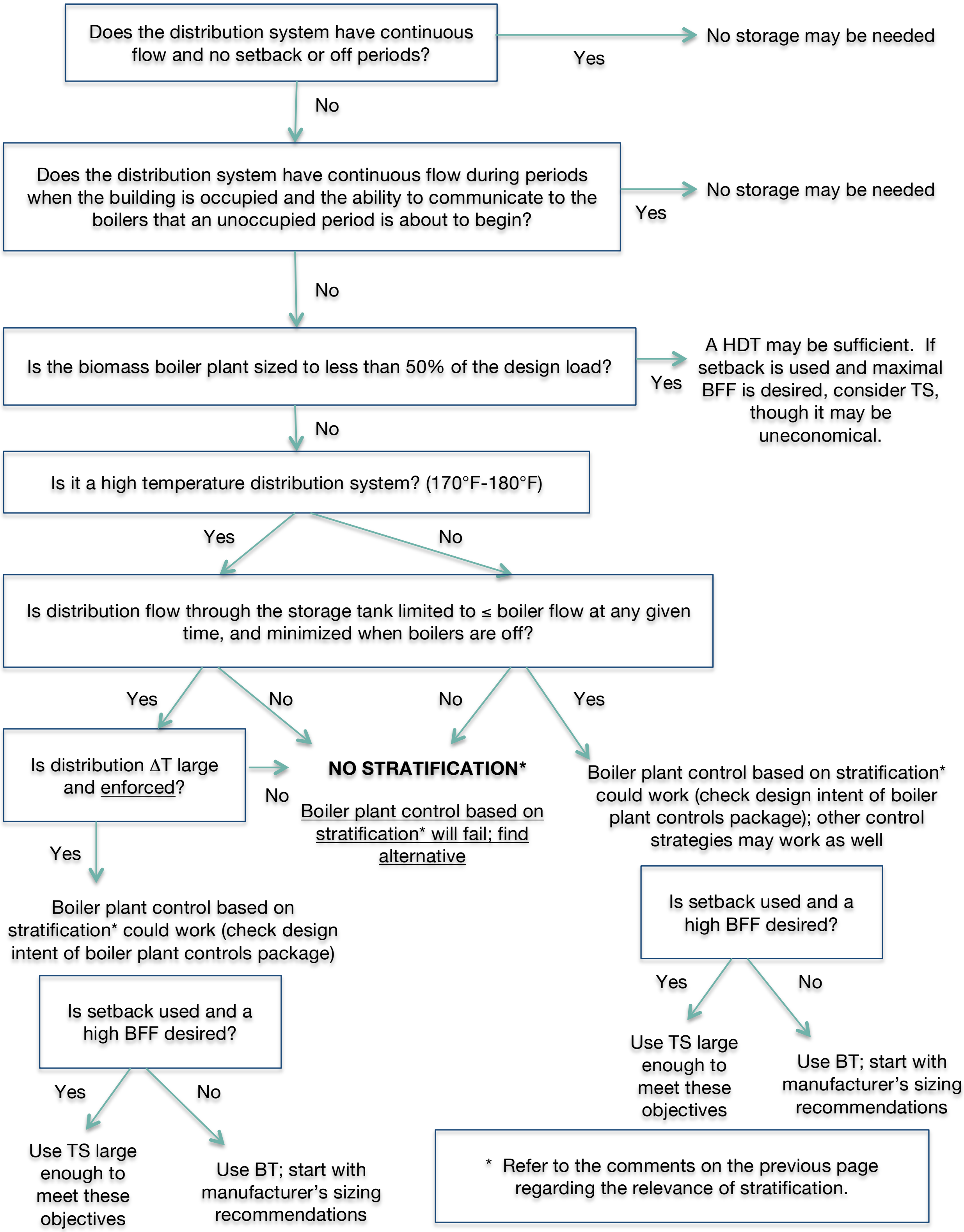
Why might the system fail? It may just have boiler plant controls designed to encounter conditions very different from those in your facility. Short-cycling and poor responsiveness are common symptoms of a mismatch of boiler plant controls and the distribution system.

Poor Performance and Stratification—a Disclaimer

Our analysis of hundreds of thousands of hours of stratification data over dozens of boiler plants has led us to the conclusion that stratification is uncorrelated with good performance, as we have defined it. You or your manufacturer may have a measure of performance that is correlated to stratification. In that case, stratification may be very important for you to achieve. Note that in the decision tree below, stratification is not easy to achieve and can only exist if many system conditions are met. Our data have indicated that it is irrelevant and not worth the effort. You need to decide if it matters in your installation.

Storage: A Decision Tree

When looking at the decision tree below, you will see that the key questions are those associated with <u>distribution temperature and flow</u> since these factors influence whether stratification will be present.* **These must be fully understood in advance, or system performance may fall far short of hopes.**



Some common calculations you may need to perform:

Heat Dump Tank (HDT):

How much heat must be removed from the boiler if operating at full output and the load is suddenly removed? How large must a HDT be to handle this safely? Is there a solution to this problem that does not involve a tank? Would it be cheaper to install a fan-coil or other means of heat dissipation if the HDT would be rarely used?

Buffer Tank (BT):

What does the manufacturer require/suggest for storage? (Remember, the manufacturer may be making temperature and flow assumptions about your distribution system that are not valid.) Again, this may be something like 2 gallons of storage per kbtu/hr of boiler output. Use this as a starting point, but make sure you know whether you have enough storage to accomplish your goals. For example, do you expect the BT to allow you to ride out periods when the boilers are off for cleaning? Make sure you plan for that, taking into account the length of time the boilers are off and total output of the boilers currently unavailable. Also, do not expect a manufacturer's BT sizing recommendation to handle what you'd need for TS for setback recovery. That's an entirely different scenario. (See also questions at the bottom of page 4 regarding tank sizing to ensure minimal run times.)

Thermal Storage (TS):

What is the size of the recovery load? How many btus may be needed to recover from setback? Given the required loop temperature and the loop ΔT, what volume of TS is required?

The size of TS may be reduced by oversizing the boiler plant, preferably by inclusion of additional boilers rather than just boosting the size of an existing boiler. (As an alternative, consider reducing/eliminating setback, particularly if a high BFF is desired and the funds are not available for TS and/or a larger boiler plant.)

Caution

An important fact to consider is that the presence of any kind of storage does not necessarily provide any safety in the event of a power outage. That scenario needs to be considered and planned for in all installations.

Other Considerations:

Many other questions are relevant and important in designing the system. Here are just a few:

1. How do you prevent your backup/peaking fossil-fuel boiler from charging your storage? This is something to avoid if your goal is a high BFF.
2. If you can isolate your storage from the system at will, you can accomplish #1 and also get a nice boost in responsiveness during recovery, as 100% of your boiler heat will go straight to the building, rather than to reheating a large volume of water in your storage.[1] Can you accomplish this?
3. How do you prevent an over-eager fossil-fuel backup/peaking system from "stealing" load that the biomass system can easily handle, perhaps given a little time?

[1] Don't assume the hot water from the boiler just skims across the top of the buffer tank to be delivered to the building! That will ONLY happen if the total flow into the tank from the boilers equals or exceeds distribution flow through the tank. Can you guarantee that?