Patterson-Kelley

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# MACH CI
## (Condensing-Indirect) Water Heating

**Abstract:** Limited pressure vessel life expectancy due to scale-up and high pressure vessel replacement costs mean that owners of condensing water heating equipment lose an unacceptably high percentage of their fuel savings through re-build and other maintenance costs. This has lead a number of our customers to ask if there isn't another way to achieve condensing efficiencies in high volume domestic water heating systems. This white paper responds to these inquiries by introducing the concept of CI (condensing-indirect) water heating in which all wear-and-tear is taken by a low cost, throw-away, plate-and-frame heat exchanger. This approach means that a customer can purchase an entirely new configuration for roughly the same cost as a pressure vessel replacement on his existing hardware, and can avoid up to 90% of future re-build costs while still achieving ultrahigh fuel efficiency.

### The Problem

ALL direct-fired water heaters scale up eventually. This occurs partly because of boundary layer phenomena, and partly because the solubility of hardness minerals in water falls with rising temperature. The pressure vessel of a direct-fired water heater, any water heater of any design from any manufacturer, has a limited life expectancy. In the end, we all know that.

This is what has given rise to the question that this paper attempts to answer. Numerous customers, particularly in hard water areas or in facilities with large domestic water demands or extremely wide load swings, are scaling up their heat exchangers in relatively short order. That's not a particularly noteworthy concern when the water is being heated with cheap, atmospheric water heaters. In fact, it's expected.

But *these* customers invested big money in ultra-high efficiency, condensing water heating equipment, lured by the promise of big energy savings. At first the promise was realized and they were happy with their investment.
The problem is that they didn't get to keep the savings. They, too, have had to replace their scaled-up heat exchangers, and they were shocked to find out how much it costs to do that for this new generation of highend equipment. Is there a way, they ask, to achieve these high fuel efficiencies without having to replace heat exchangers?

### Defining Requirements

Before presenting the solution, let's be clear about our objectives. There are three key requirements.

1. We must minimize the ownership cost of condensing water heating equipment. It does no good to save fuel dollars if we raise re-build and maintenance costs by an equivalent amount. The owner is no better off. Condensing water heating equipment is more costly than any of the conventional atmospheric or fan-assisted options. The equipment we use has to last; in fact, it needs to have an indefinite life expectancy.

2. The solution must be an economic choice with a reasonable payback. Operating efficiencies must range from the low to high 90's, and should still be high during peak demand



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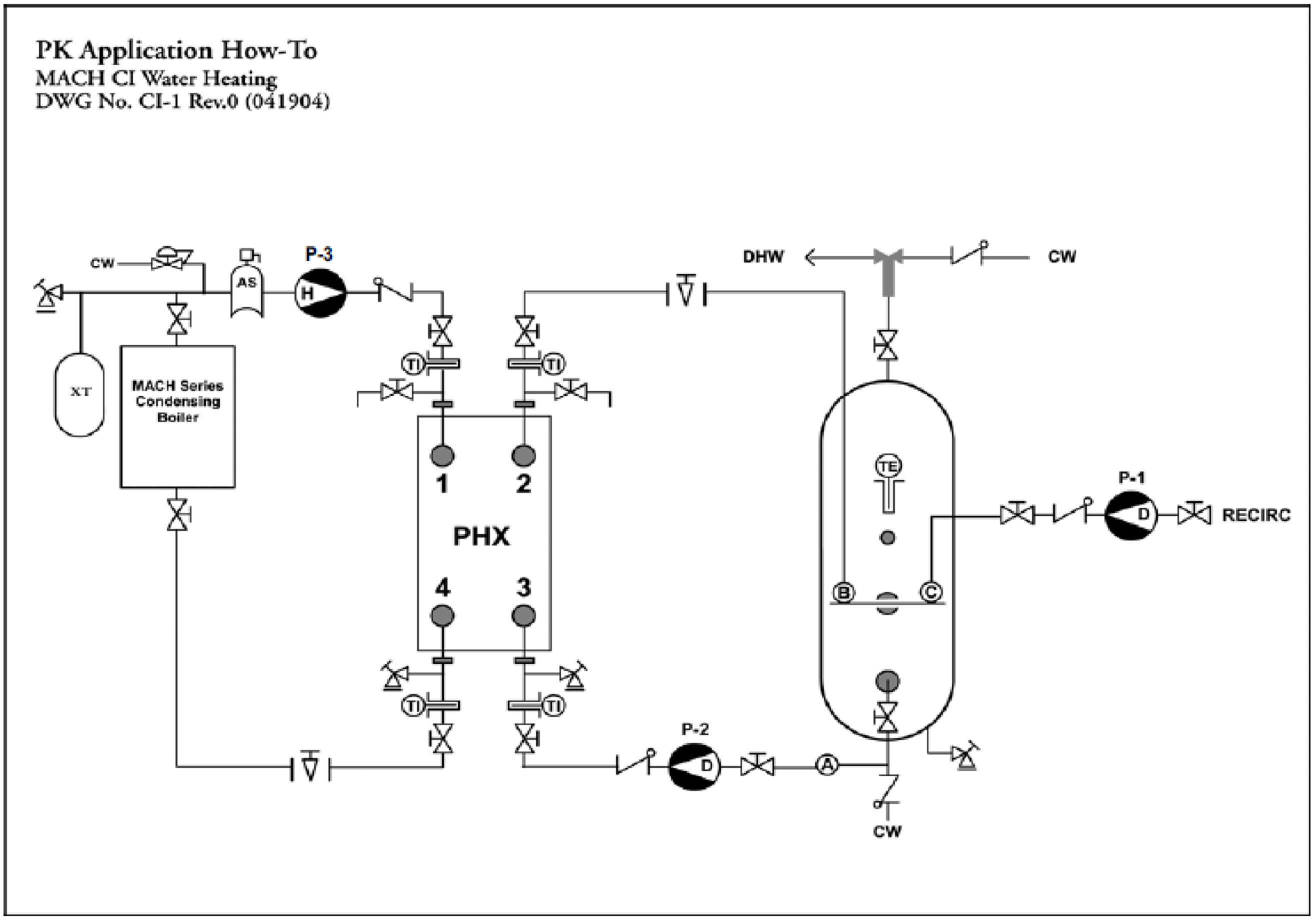


*Figure 1. This is the basic MACH CI water heating system. Note the match points A, B and C. These are the basic connection pointsfor all of our system schematics.*

when fuel usage is greatest.

3. The cost of implementing the solution should compare favorably to the re-build cost of a direct-fired condensing water heater. This gives the owner an economic alternative when he discovers that he owns a system that has become a long-term economic liability.

### The Solution

Recent years have seen the introduction of low cost, plate-and-frame heat exchangers of brazed construction. As more and more manufacturers have entered the business, and as many European manufacturers (who at first manufactured their product for private labeling by American companies) have begun to market their products directly to the American trade without OEM markups, costs are lower than ever. You can now buy one of these heat exchangers for less than the price of a good gate valve. Heat exchangers for domestic water service scale up eventually, so it seems reasonable to use something that provides good service life at minimal cost. These heat exchangers are ideally suited to our purposes.

The proposed system, which we call CI (for condensingindirect) water heating, is illustrated in schematic form in Figure 1. CI water heating is accomplished by creating a closed loop heating system that goes from boiler to heat exchanger and back to boiler. Domestic water is circulated through the other side of the heat exchanger and stored in a conventional domestic water storage tank. Piping is arranged so that domestic water enters the heat exchanger at the coldest possible temperature, though the system is designed so that achieving high boiler efficiency does not overly depend upon this.

It is customary to make a graphical representation of the temperature requirements of a heat exchanger prior to sizing. Figure 2 shows what we are attempting here for a common application. Domestic water enters at 40˚F and leaves at 125˚F. Heating water enters at 130˚F and leaves somewhere between 104˚F to 105˚F. Note that the leaving heating water temperature is lower than the leaving domestic water temperature. Provided that the entering heating water temperature is higher than the leaving domestic water temperature, there is no problem with doing this provided the heat exchanger is selected for the duty. It requires a special arrangement of heat transfer surface (called "counterflow"), and all of the heat exchangers we use in CI water heating are chosen for this type of duty.

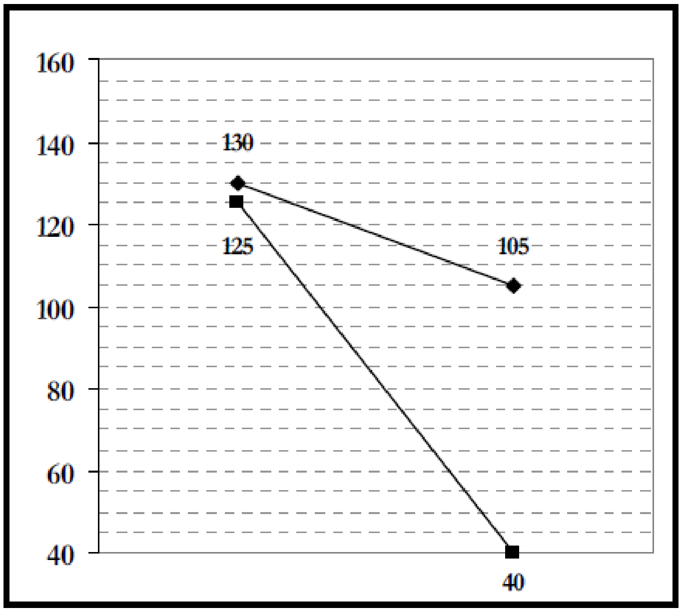


*Figure 2*

Note also that the entering heating water temperature and the leaving domestic water temperature are only 5˚F apart (130˚F vs. 125˚F). This is what is meant by temperature approach, and the approach will always be small in these systems. If you subtract the entering heating water temperature from the leaving domestic water temperature you get 5˚F. If you subtract the entering domestic water temperature from the leaving heating water temperature you get 55˚F. These two temperatures are called, respectively, the lesser and greater temperature differences, and are used to calculate the raw value of the log mean temperature difference (LMTD), a key parameter in heat exchanger surface area calculations. The LMTDs will always be substantially lower than in conventional domestic hot water heat exchanger applications.

Under light load conditions the heat exchanger duty will change in an interesting way. Note that the pump on the domestic water side of the heat exchanger (P-2 in Figure 1) draws water from the cold water makeup line. What happens when the demand for domestic hot water is small, the tank is merely recovering from a large surge load, and only a tiny amount of cold water is entering the system? Under these conditions the flow through P-2 exceeds the entering cold water flow rate, and the balance of the water demanded by

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the pump will be drawn from the tank (flow will reverse in that short section of piping). As the tank approaches setpoint, the temperature of the domestic water entering the heat exchanger will rise. Figure 3 offers a snapshot of a low load condition like this.

Note that the domestic water now enters the heat exchanger at 115˚F (it continues to leave at 125˚F). The heating water now enters at 130˚F and leaves at somewhere near 126˚F. The difference between the leaving heating water temperature and the leaving domestic water temperature is about 1˚F! This is a very narrow approach for any heat exchanger. But while this has become a narrow approach condition, it is no longer a temperature cross situation: the exiting heating water temperature is still higher than the leaving domestic water temperature. It turns out that if the heat exchanger has enough surface to achieve a temperature cross at high fire, it usually has enough surface to handle a narrow approach without a temperature cross at low fire (though you still have to check to be sure).

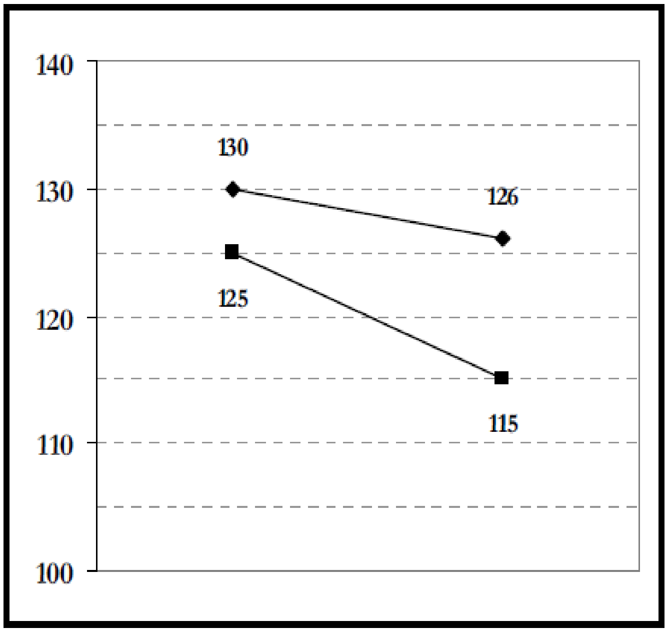


*Figure 3*

What's critical here is that there is some important tradecraft associated with heat exchanger selection. The skeleton key to CI is a thorough understanding and mastery of the conditions seen by the heat exchanger. If you can define quantitatively absolutely everything the heat exchanger will be called upon to do, regardless of boiler firing rate, you can do CI water heating. The heat exchanger must be able to achieve a temperature cross when that is required, yet still have enough surface to transfer whatever the boiler puts out into the domestic water, even at a low approach or LMTD - however low they happen to be. Patterson-Kelley has been in the heat transfer business since 1880, and we know how to evaluate challenging situations like this. We have made our standard CI heat exchanger selections with all of these considerations in mind.

The heating water supply temperatures used in our standard CI water heating system configurations are not arbitrary. First, we want to heat domestic water using heating water at a temperature sufficiently low to create full condensation in the boiler. Second, as in any indirect water heating system, the heating water must be warmer than the required domestic water temperature (obviously). Doing both of these things *at the same time* (!) is the essence of CI water heating. Fail to do one or the other, and CI water heating won't work.

Our standard equipment selections are based on four standard sets of conditions as shown in Figure 4.

| | EWT | Tank | SWT | Boiler |
|---|---|---|---|---|
| 1 | 40°F | 125°F | 120°F | 130°F |
| 2 | 50°F | 125°F | 120°F | 130°F |
| 3 | 40°F | 115°F | 110°F | 120°F |
| 4 | 50°F | 115°F | 110°F | 120°F |

*Figure 4*

In developing these systems we have assumed that a thermostatic mixing valve is installed at the outlet of the storage tanks (because local codes increasingly require them for anti-scald protection), and that water is stored at 5˚F above the required delivery temperature. If a mixing valve is not used outputs will be slightly greater and the boiler operating temperature can be 5˚F lower, resulting in an increase in boiler efficiency. The absence of a mixing valve is no impediment.

We have also assumed that the CI concept is best suited



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to domestic hot water systems operating between 110˚F and 120˚F, which, due to recent code changes, covers an increasingly larger percentage of applications. The more conventional systems operating at 140˚F operate outside the condensing range and can achieve condensing efficiencies only part of the time. For this reason they are not covered by this paper. (An interesting aside: the heat exchangers actually get larger as you move from the top to the bottom of Figure 4, exactly the opposite of what you might expect.)

## How To Size A System

There are two system parameters required for sizing a CI domestic hot water heating system: peak GPM and peak GPH. Both parameters can be estimated from the ASHRAE Handbook.

Peak GPM is estimated using the section of the chapter on Service Water Heating that deals with instantaneous and semi-instantaneous type equipment. Your fixture count is translated into fixture units, and the Modified Hunter Curves translate fixture units into peak GPM. This is just like sizing a PK Compact water heater.

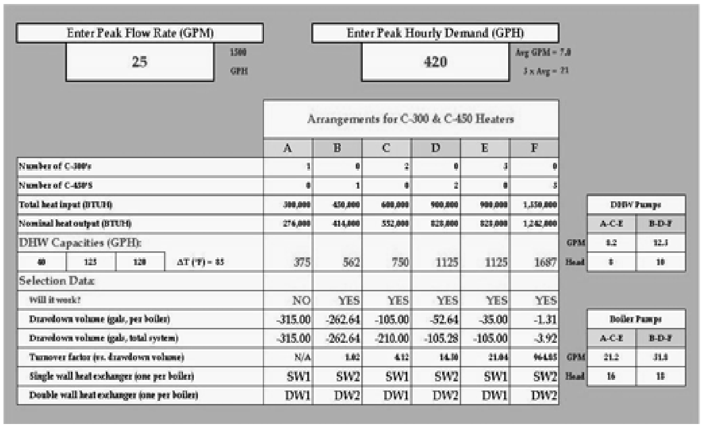
Peak GPH can be estimated from the table of hot water use for various types of buildings. You should use the values from the Maximum Hour column. The table is easy to use because its values are shown in gallons per person, per unit, per bed, per student, per apartment, for each type of building shown. You might have to add to these values additional gallons for special requirements such as washing machines, etc. The process is straightforward and uncomplicated.

Consult the index and look for Service Water Heating. There are some truly useful charts for GPH estimation that appeared in the 1976 edition that have been omitted from later editions. It doesn't really matter, though, as any recent edition provides all the information you will need to estimate your domestic water load.

Armed with these two values, system sizing and selection are easy. Simply enter these two values into the appropriate calculator and the screen will indicate the number of boilers required, the boiler size, the heat exchanger model to be paired with each boiler, the minimum effective storage volume required, and the sizes of the both the boiler and domestic water circulating pumps.

Figure 5 shows the calculator screen. MACH CI water heating systems are currently available for loads from 375 to 2,256 GPH, and actual capacity depends upon service conditions. Use the calculator to see if a MACH CI system can handle the application. Pair the calculator output with the appropriate system piping schematic selected from the system diagrams included with this paper, and your requirements are complete.

We have opted for the simplest possible control schemes, and controls that are readily available, simple to set up and operate, reliable, well known to, and accepted by, the trade, and relatively cheap. The Honeywell T775 and Tekmar boiler controllers meet these requirements, and should be selected to provide setpoint control with one stage of heat for each of the boilers in the system. All we need to do is set up on-off staging control based on the tank temperature. When a boiler is energized it will operate to maintain its own setpoint (see Figure 4, and reduce by 5˚F if there is no mixing valve). It's important to adjust the operating limit controls on the boiler so that they don't fight the on-off signal from the tank controller. Any additional control capabilities that might be required are built into the on-board controls of MACH series boilers.



Enter Peak Flow Rate (GPM): 25 (1500 GPH)

Enter Peak Hourly Demand (GPH): 420 (Avg GPM = 7.0; 3 x Avg = 21)

| | Arrangements for C-300 & C-450 Heaters | | | | | |
|---|---|---|---|---|---|---|
| | A | B | C | D | E | F |
| Number of C-300's | 1 | 0 | 2 | 0 | 3 | 0 |
| Number of C-450'S | 0 | 1 | 0 | 2 | 0 | 3 |
| Total heat input (BTUH) | 300,000 | 450,000 | 600,000 | 900,000 | 900,000 | 1,350,000 |
| Nominal heat output (BTUH) | 276,000 | 414,000 | 552,000 | 828,000 | 828,000 | 1,242,000 |
| DHW Capacities (GPH): | | | | | | |
| 40 / 125 / 120 / ΔT (°F) = 85 | 375 | 562 | 750 | 1125 | 1125 | 1687 |
| Selection Data: | | | | | | |
| Will it work? | NO | YES | YES | YES | YES | YES |
| Drawdown volume (gals, per boiler) | -315.00 | -262.64 | -105.00 | -52.64 | -35.00 | -1.31 |
| Drawdown volume (gals, total system) | -315.00 | -262.64 | -210.00 | -105.28 | -105.00 | -3.92 |
| Turnover factor (vs. drawdown volume) | N/A | 1.02 | 4.12 | 14.30 | 21.04 | 964.85 |
| Single wall heat exchanger (one per boiler) | SW1 | SW2 | SW1 | SW2 | SW1 | SW2 |
| Double wall heat exchanger (one per boiler) | DW1 | DW2 | DW1 | DW2 | DW1 | DW2 |

| DHW Pumps | A-C-E | B-D-F |
|---|---|---|
| GPM | 8.2 | 12.3 |
| Head | 8 | 10 |

| Boiler Pumps | A-C-E | B-D-F |
|---|---|---|
| GPM | 21.2 | 31.8 |
| Head | 16 | 18 |

*Figure 5. This is a sample of an output screen for the calculator referenced in the text. All system selections are based on this calculator.*

## Final Considerations

1. Engineers and code authorities differ in their opinions on

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whether domestic water should be stored at high temperatures to control the growth of microbiological contaminants. Often the domestic hot water storage tanks represent but a small fraction of total system volume, and many engineers question whether storage temperature matters as much as the presence of stagnant zones in the storage tank. They point to the risk of injury from scalding should the blending valve fail or provide poor control due to light loading, and think that this should be the focus since it represents an every-day hazard. We offer no opinion on the issue, and leave it to the discretion of the professional engineer whose responsibility it is. An increasing number of systems are being operated at lower temperatures, however, and this
paper answers the technical question of how to do it.

2. Symmetry in tank piping is an important design requirement as it is important to equally load each tank and promote equal turnover rates. Experience indicates that professional plumbers who practice good tradecraft have utilized such piping practices for decades. It seems most practical is to build upon established tradecraft that is widely practiced.

3. The drawings are schematic. Always check the heat exchanger submittal drawing to determine the actual nozzle orientation for a specific installation.

4. Always contact your authorized Patterson-Kelley representative for support in developing plans and specifications. They can assist in selecting the best schematic for your specific project, can support you with suggested specifications that are sensitive to local code requirements, and can provide you with wiring schematics and other system details.

Drawings & Tools
MACH CI Calculator (Excel format)
CI-1: One boiler, one heat exchanger, one tank
CI-2: Two boilers, two heat exchangers
CI-3: Three boilers, three heat exchangers
CI-4: Two tank configuration
CI-5: Three tank configuration
CI-6: Four tank configuration
For a system with one boiler and one tank, use drawing CI-1. For all other systems use one schematic for the boiler and heat exchanger arrangement plus one schematic for the desired tank arrangement. For instance, if you have two boilers but are going to utilize an existing three tank storage system, combine drawings CI-2 and CI-5, and connect the piping at the three match points (A, B and C). "A" represents the cold water supply for the domestic water side of the heat exchanger. "B" represents the hot water leaving the heat exchanger. "C" represents the point of connection for house recirculation. Match A to A, B to B, and C to C.



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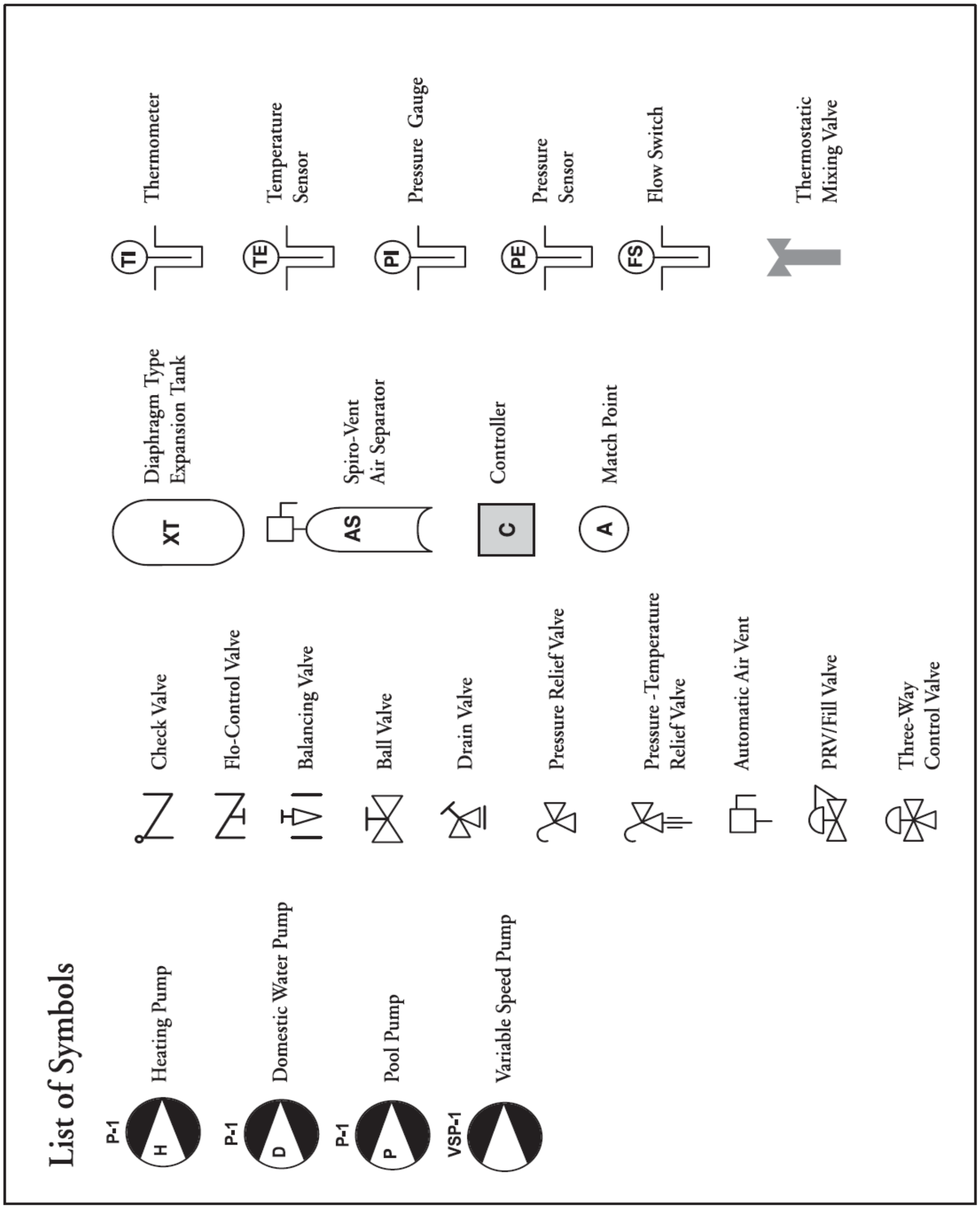


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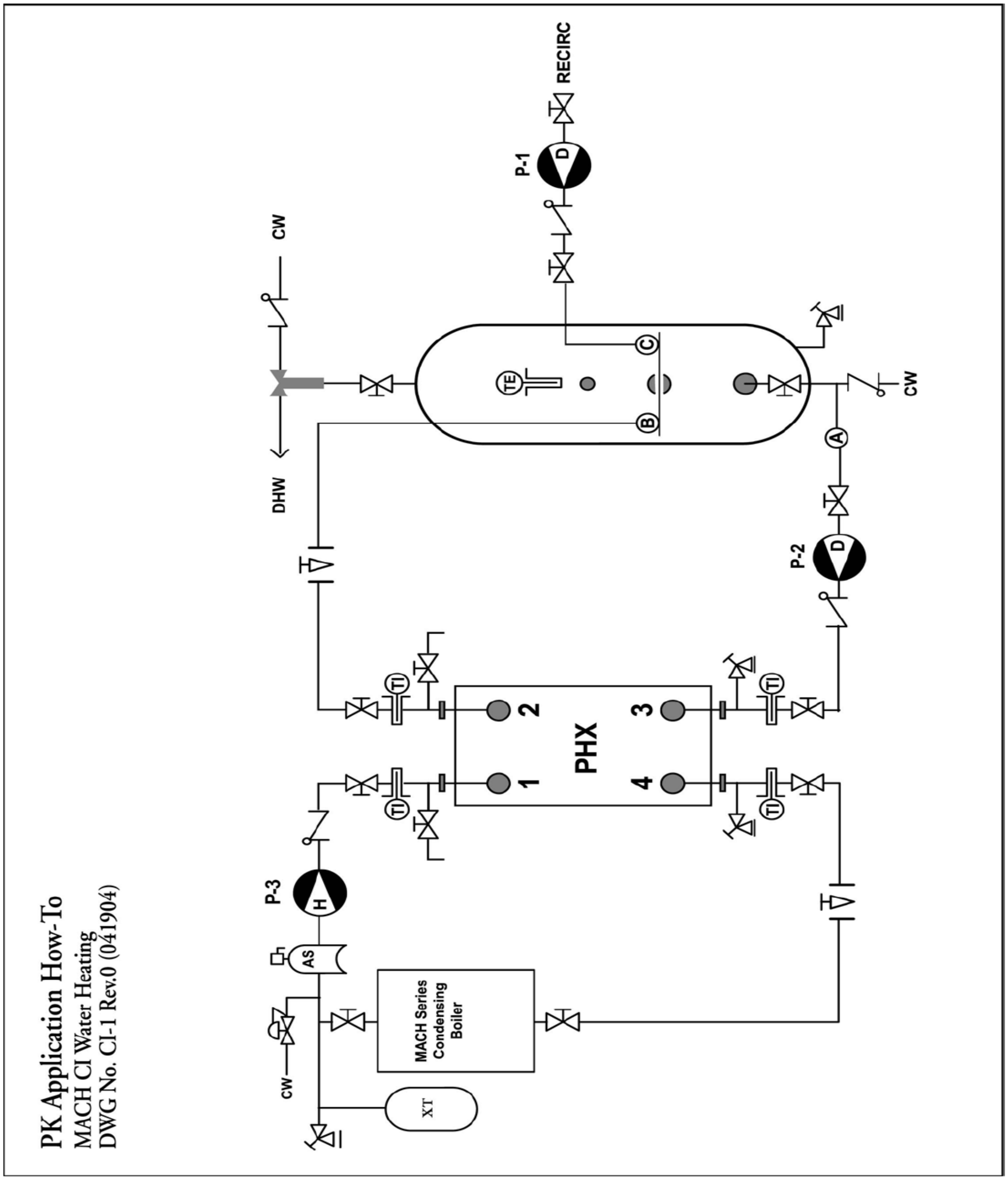
PK Application How-To
MACH CI Water Heating
DWG No. CI-1 Rev.0 (041904)
RECIRC
P-1
CW
DHW
TE
P-2
P-3
PHX
AS
MACH Series Condensing Boiler
XT

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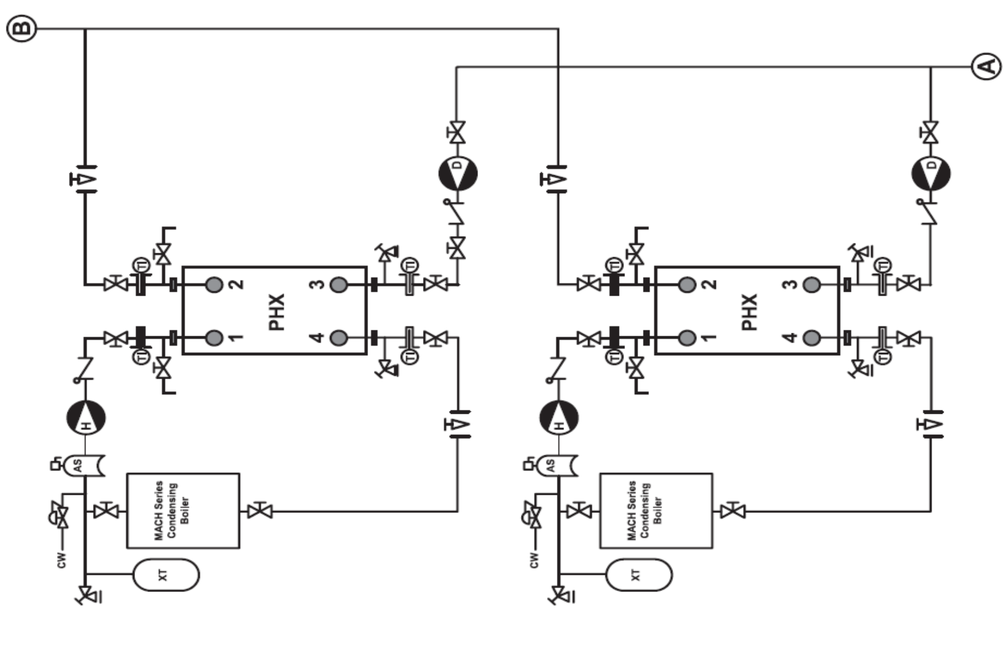


PK Application How-To
MACH CI Water Heating
DWG No. CI-2 Rev.0 (041904)

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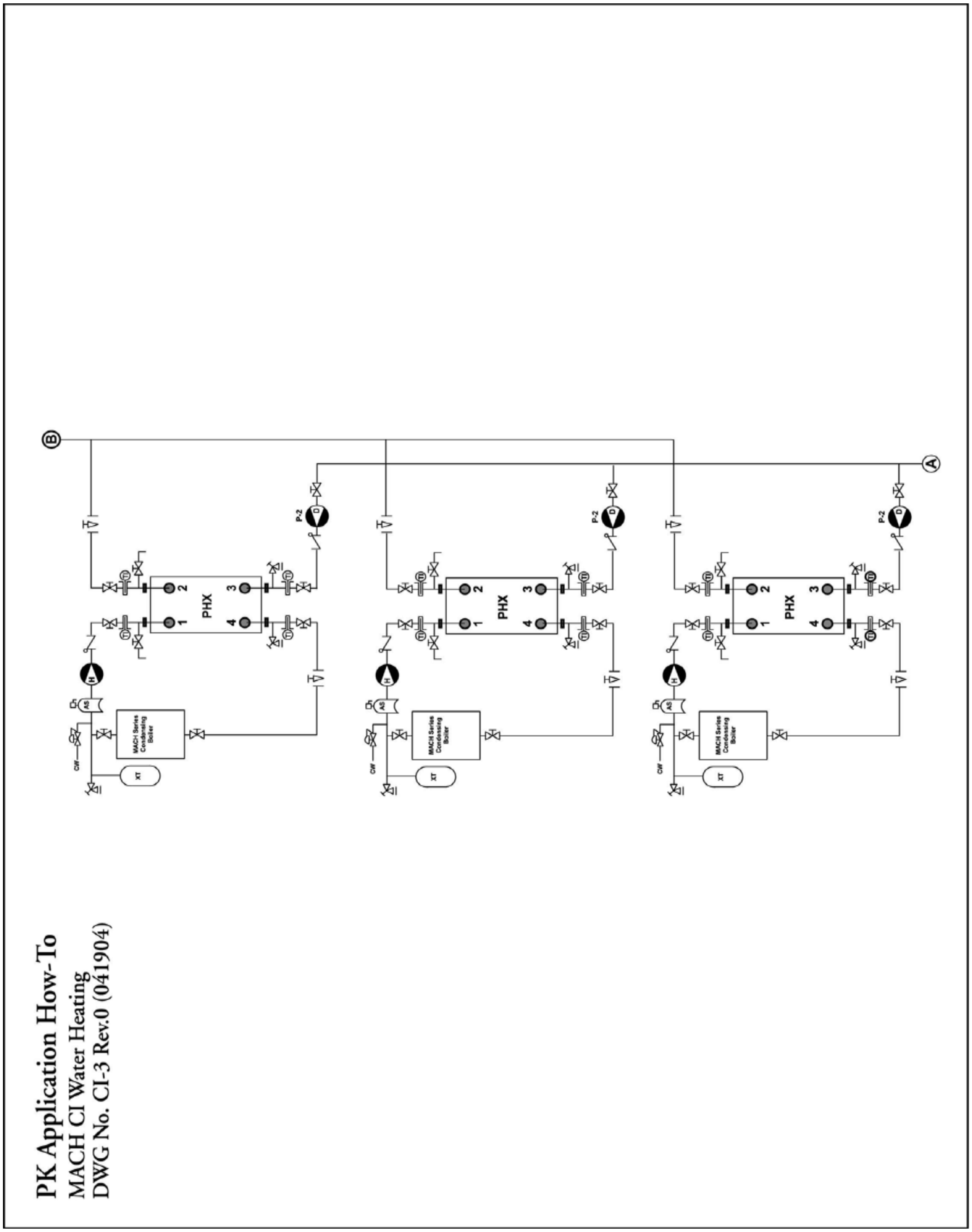


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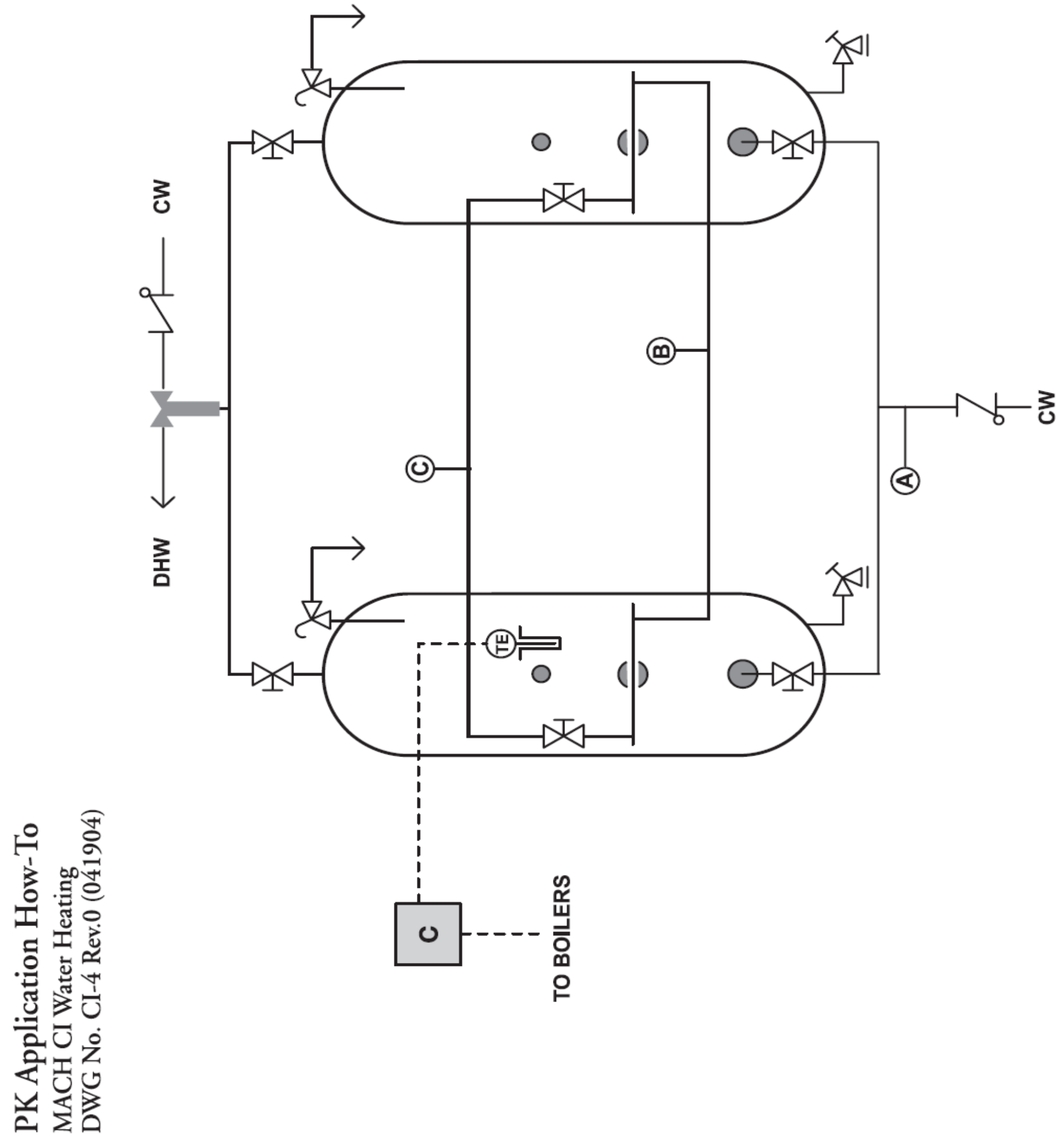
PK Application How-To
MACH CI Water Heating
DWG No. CI-4 Rev.0 (041904)
CW
DHW
C
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TO BOILERS

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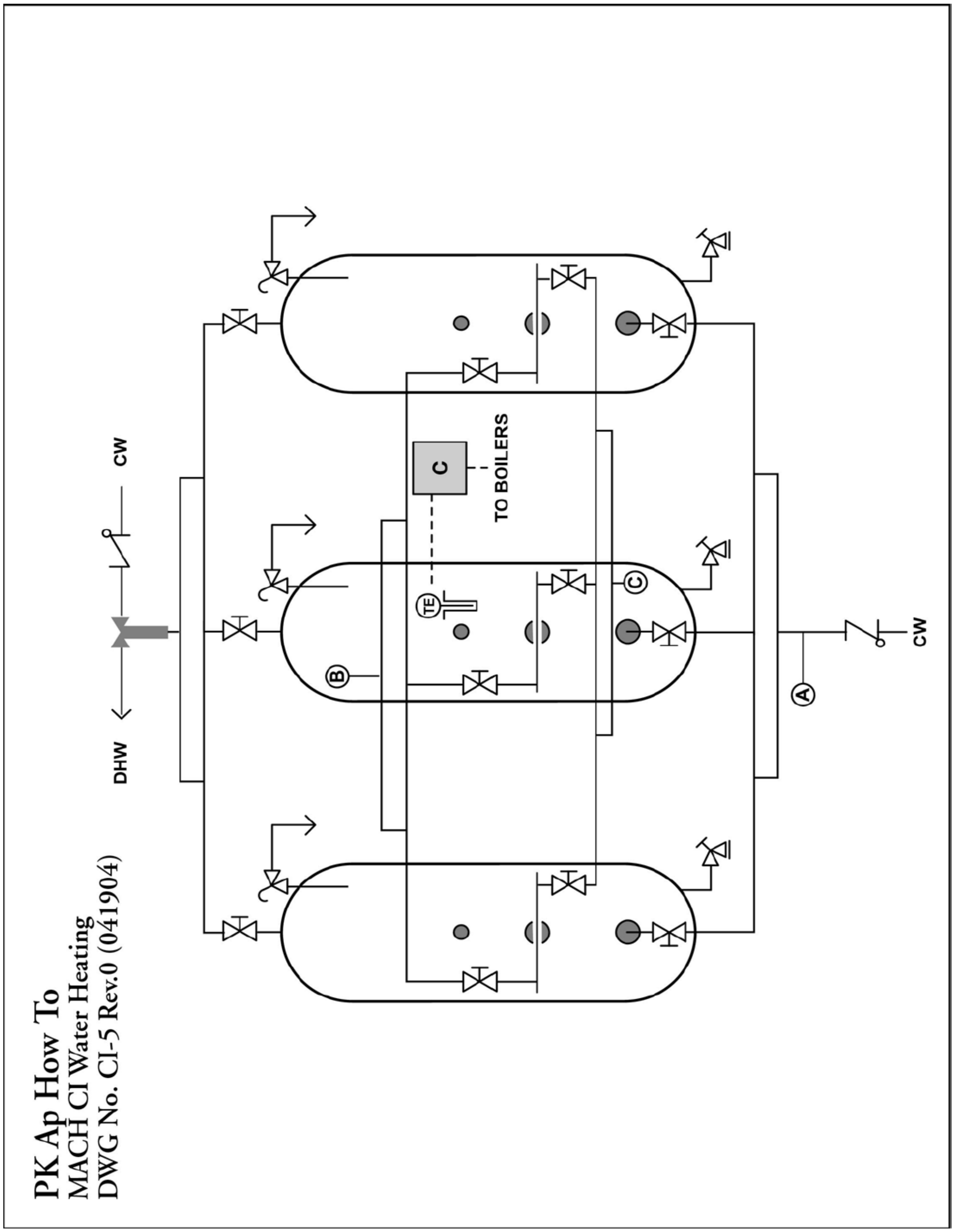


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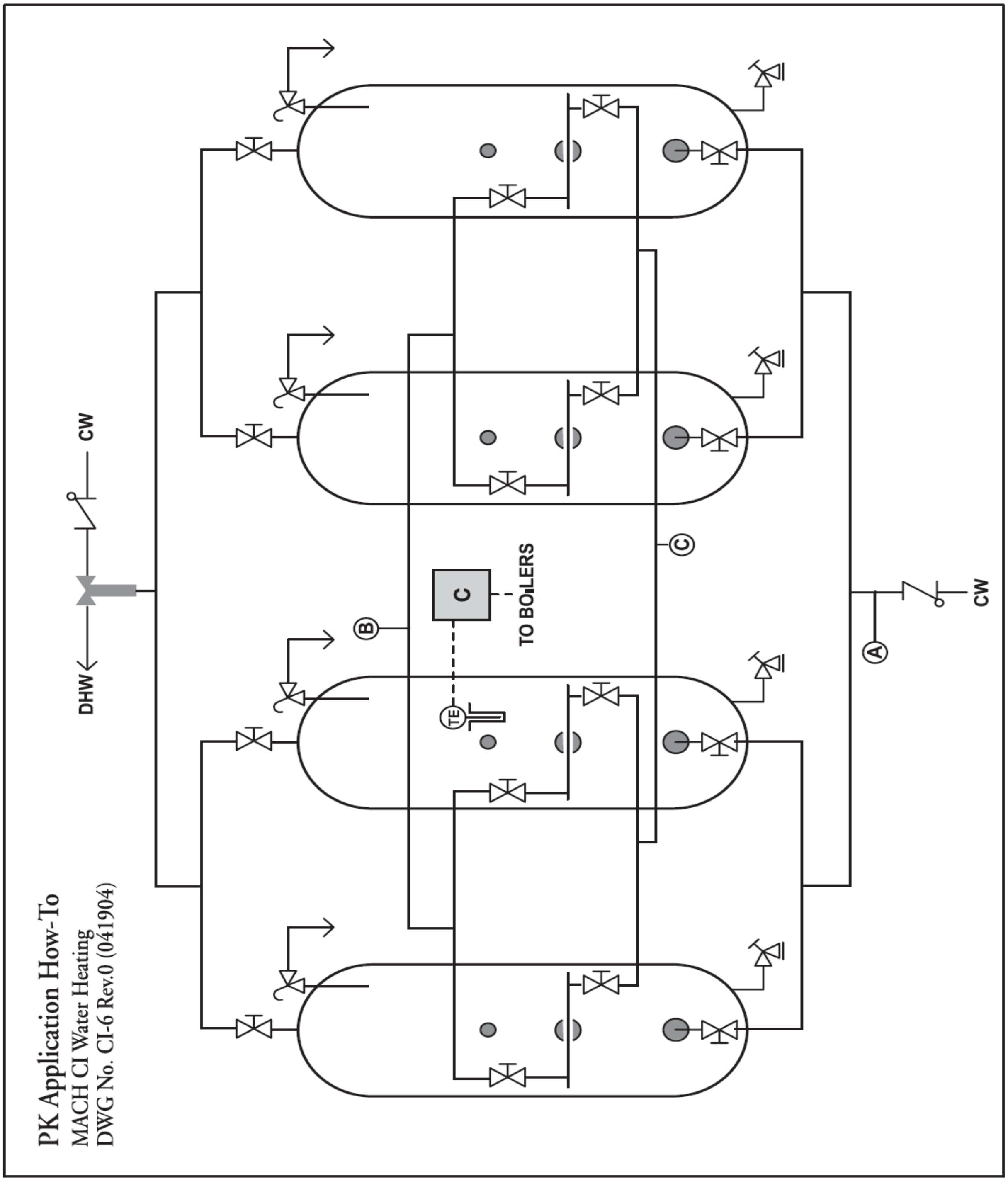


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