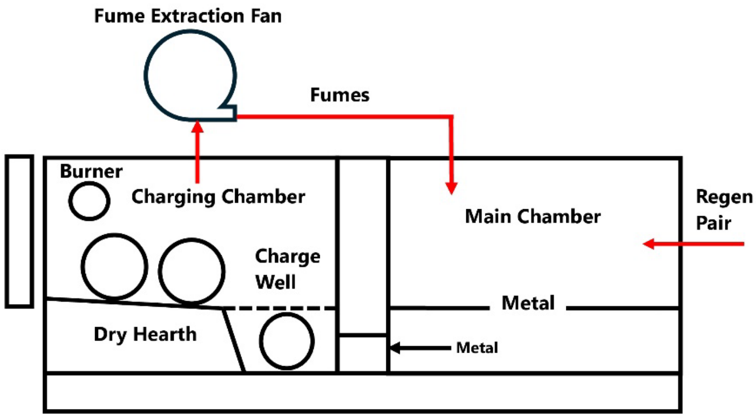
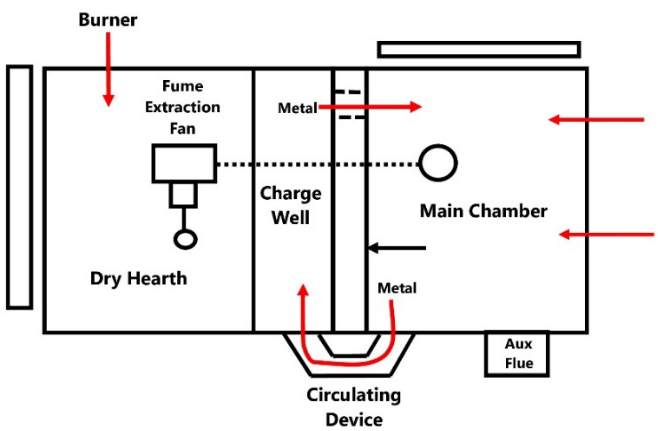
MULTI-CHAMBER FURNACES

In recent years, multi-chamber furnaces have been utilized to process contaminated scrap with higher levels of organic or inorganic content. The system uses a combination of dry hearth and well melter design.



MC-1



MC-2

MC-1 and MC-2 show the typical arrangement of the two chambers. The dry hearth and charge well are enclosed in the charge chamber. The scrap is charged in this chamber where the organics/coatings are volatilized (removed) from the scrap. The fume extraction fan transfers the hot gases/contaminants to the main chamber for oxidizing and removal. The main chamber holds a pool of hot, liquid metal. The circulating device moves hot metal into/through to the well. The circulated hot metal is the source of heat to melt the scrap charged into the well. This process is very similar to a standard well charged melter.

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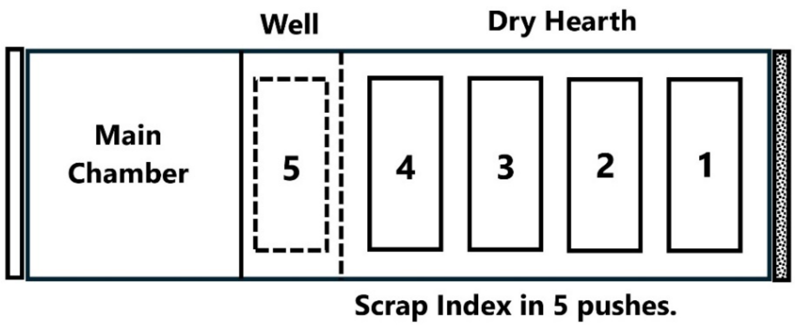
Dry Hearth

The contaminated scrap is placed on the dry hearth and is pushed over time into the well.

1) The dry hearth is long to ensure that wet metal cannot submerge before water is removed. Typically, the metal is indexed/pushed 3-4 times before dropping into the well.



MC-3

2) The charge requires sufficient time on the dry hearth to remove water and volatilized contaminants.

3) The indexing/pushing of the scrap should agitate/mix the pile as it is moved to slowly expose all the metal surface area to the hot gases to volatize the contaminants (organics).

The level of decontamination achievable is dependent on:
- Temperature
- Hot gas circulation
- Time

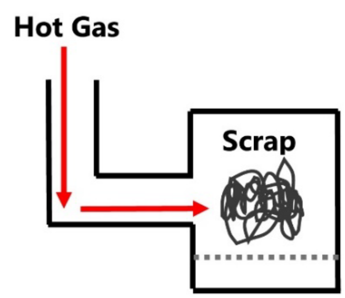
Typically, the dry hearth chamber operates from 900°F (480°C) to 1000°F (540°C) operating at too high a temperature will cause the metal to soften or melt and resolidify, called slagging. This slagging will decrease the voids (open area) in the scrap pile limiting hot gas penetration and releasing of volatized organics, which is the main function of this dry hearth. The fumes/volatized organics are extracted mechanically and injected into the main chamber for oxidation. The fumes provide energy in the main chamber furnishing modest fuel savings at times. Fume destruction in the main chamber can be challenging (more on this later).

The delacing/decoating process is typically achieved in 2 ways:

1) <u>Roasting</u>
The metal is index in a furnace held at the design temperature by heat from the open well and a <u>burner</u> providing hot POC and <u>some</u> recirculation. The chamber has minimal oxygen in the atmosphere to avoid the atmosphere reaching an explosive mixture as the organics

boil off. The burner is a heat and an ignition source should the atmosphere near a combustible mixture. The mixture would ignite before a potentially dangerous build up occurs. This method of organic removal has the advantage of a slower volatilization of the organics as the scrap pile heats up. The slow release of organics is beneficial for efficient fume destruction in the main chamber. There needs to be a low level of O_2 in the chamber. This O_2 is generally supplied through the burner. Typically, the atmosphere should operate with 5-6% O_2 to aid in carbon removal and provide oxidation of some of the organics to add heat to the process.

2) <u>Recirculation</u>
The second method utilizes a hot gas generator to produce a high volume, high excess air preheated air stream that is blown into the chamber to recirculate through the scrap pile.



MC-4

The high volume gas stream:
a) Provides considerable recirculation around/through the scrap to enhance the volatilization process.
b) The gas stream is maintained with excess air to avoid an explosive condition in the chamber (below LEL).

Note: A small burner is still recommended to act as an ignition source before a significant buildup of combustible could occur.

c) This method is more efficient than roasting but:
- There is a greater volume of gases passed through to the hot chamber.
- Volatilization potentially occurs rapidly making periods of very high organics to be processed in the main chamber.
- The level of O_2 in the gas stream may prove detrimental, potentially increasing metal oxidation/loss.
- Temperature control in the charge chamber can be a challenge. If a significant amount of combustion occurs between the organics and the O_2 in the hot gas. The temperature can rise to an undesirable level (melting, slagging and metal oxidation will occur).

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Main Chamber

The main chamber is the primary source of heat for the melting process. The metal is heated in the chamber and recirculated out through the charge well and returned to the main chamber for reheating.

The melt rate is determined by:

1) Main chamber bath surface area and the differential temperature of the heat source to metal.
2) Pump capability to move metal through the well.
3) Preheated metal temperature.
4) Charging rate in the well.

Note: See well-charged booklet for further explanation.

The charge/push rate of scrap into the well is a major factor. When the well is overcharged, the hot metal circulation decreases with a subsequent decrease in melt rate (charging baled scrap can significantly limit melt rate). In addition to providing heat to the process, the main chamber also operates as the oxidizer/fume incinerator. Efficient fume destruction requires adequate time, temperature, turbulence (mixing) and oxygen availability.

Temperature is generally not an issue as the chamber operates at 2150°F (1175°C) +/-. Time and turbulence become the more critical design issues. Turbulence is necessary to ensure the oxygen and combustible elements meet in the time available.

Burner type and placement along with flue sizing and location are important but determining the source of O_2 is the starting point. There are 3 typical sources of O_2:

1) If the charging/delac chamber is utilizing the "recirculation" method, there is often sufficient O_2 in the fume stream.
   a) Advantages.
      - If the O_2 level is too low in the fume stream, it can be adjusted at the hot air generator.
      - O_2 and combustible are mixed well entering the main chamber.
   b) Disadvantages
      - The volume of the fume stream is greater than the roasting option. This potentially decreases retention time in the hot chamber, increases flue sizing and impacts bag house capacity.
      - It is difficult to determine the O2 level for adjustment. Measuring O_2 in the fume stream is difficult and costly. Fluctuating temperatures and particulate make sensor selection/installation a challenge. At best, the system is a maintenance issue.

- During periods of low levels of combustibles in the fume stream, the O_2 levels in the fume stream may be very high. The excess O_2 in the main chamber will increase fuel consumption, increase potential for corundum build up and increase potential for metal loss.

2) O_2 can be added by adjusting the fuel/air ratio of the burner system.
    - Charge chamber auxiliary burner can be adjusted to influence the level of O_2 in the chamber. Depending on burner sizing, the effect is limited.
    - Adjusting the ratio of the main chamber burners can have a significant effect and aid in mixing of the POC and fumes in the main chamber.

3) Additional air jets can be added to the main chamber. The air jets should be located to:
    a) Enhance mixing with the fume stream and provide the O_2 required.
    b) Avoid mixing or disrupting the burner flame/oxidation envelope.

    Adding air in excess of what is required (O_2 level) may create additional concerns:
    - Potential to increase NOx formation.
    - Increased fuel consumption.
    - Increased flue gas volume to the baghouse/filter.

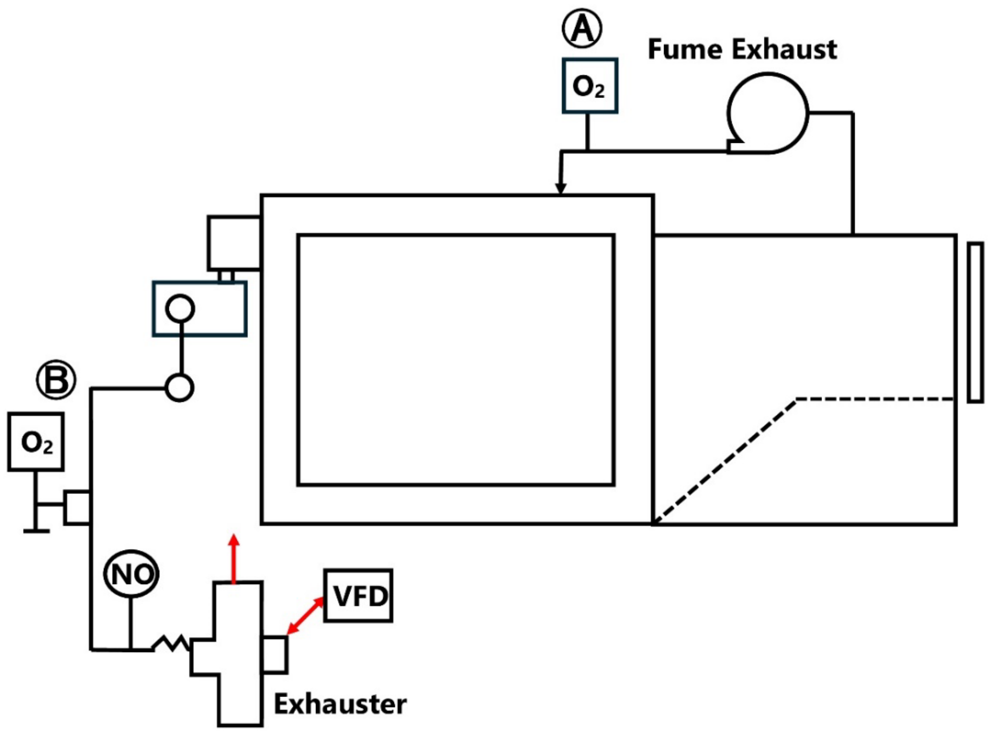
4) Utilizing pure oxygen to achieve the necessary O_2 level offers benefits in performance.
    - Elimination of the N_2 (75%) that accompanies the O_2 in an airstream reduces the potential for both NOx formation and increased fuel consumption.
    - O_2 concentration increases, raising the potential for oxidation of the fumes.
    - Decreases flue gas volume to baghouse. Offsetting the advantages is the cost of the oxygen.

The difficult part is determining the level of oxygen required:
- An O_2 level of 5%-8% is generally required in the charging/delac chamber. This varies continuously with the rate of volatilization of the contaminants and the level of oxidation occurring in the chamber.
- The main chamber should operate with a minimum of 1%-2% O_2 in the flue gas. This will vary with the level of contaminants.

Operating an O_2 analyzer in this atmosphere is a maintenance issue. Low temperature analyzers are economical, but in general, are limited to a maximum temperature of 1400°F (760°C). To safely operate, an eductor or porous filter is required. This presents a maintenance issue caused by frequent plugging with particulate. The insitu units that operate at higher temperatures are considerably more expensive, and the probe/sensor is still subject to fouling from contaminants in the flue gas stream.

Maintaining the O_2 level in the charge/delac chamber and main chamber is essential for a quality delac process and efficiency. As previously discussed, a 5%-8% O_2 level is necessary for quality delacing. Little or no O_2 in the atmosphere leads to carbon residue on the material which may lead to metal loss from overtemperature conditions if charged with aluminum scrap. Excess O_2 increases the potential for oxidation of the molten metal and initiates premature burning of the organics potentially creating elevated temperature conditions and metal oxidation.

Locating O_2 Probes



MC-5

Locating a probe at Ⓐ on the fume duct into the main chamber is the most useful and the greatest challenge. A reliable reading at this point:

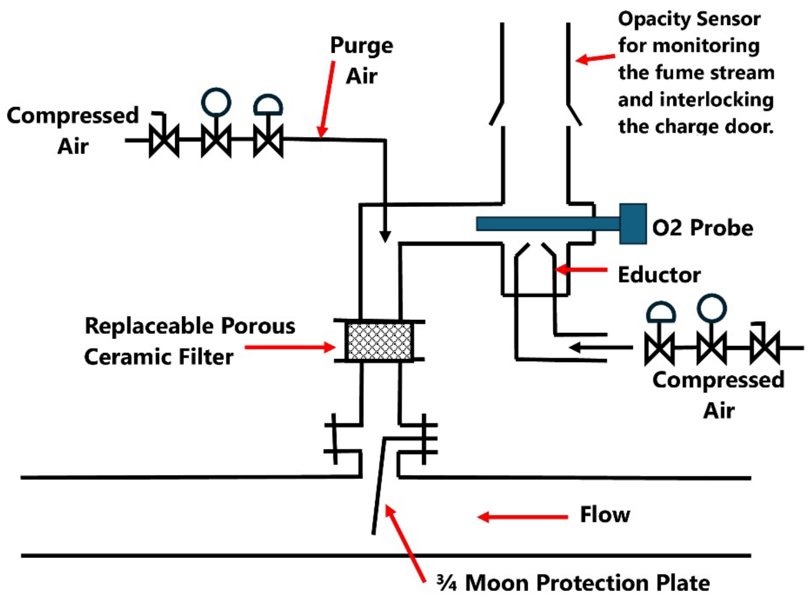
- Indicates the O_2 level in the charge/delac chamber.
- Provides indication of the makeup O_2 required in the main chamber.

Installation of a probe at Ⓐ requires some consideration:

- Will it just be a read only?
- Does it need to be continuous?
- Can the information be used to make meaningful adjustments?

As read/log only, it will provide historical data on the delac chamber operation, help in determining charging practices and identifying the good versus poor operating days.

Is continuous sampling necessary? I suggest it is not. The process does not change that fast. If it does, there is <u>no</u> chance of taking corrective action that would have immediate results. Sampling every 60-90 seconds would allow a corrective measure to be applied and time for it to take effect and results be measured. Intermittent sampling will also reduce the plugging issue at the sensor. A <u>typical sample</u> would be taken every 60 seconds for 10 seconds. The 10 second average is logged.



MC-6

Sensor installation should be primarily concerned with ease of maintenance. Installing a remote probe as shown in MC-6 utilizes a low temperature probe with an eductor to pull a sample across the sensing element. There is a replaceable ceramic filter to minimize particulate fouling of the sensing element and shield the probe from high temperatures. After a sensing period, purge air is injected back through the filter to help clean it and keep the assembly cool.

Information from O_2 sensor can be used to adjust the atmosphere in the charge/delac chamber. The O_2 level will fluctuate considerably and <u>not</u> change quickly. Having some control to maintain a range suitable for the process is beneficial. Controlling O_2 in the main chamber is less challenging, but actual control is sluggish. Corrective actions seldom result in timely response. Corrective action taken for more immediate results will create an oscillating p.v. and subsequent "hunting" by the control system.

There are two options for locating the O_2 sensor in the main chamber:

- Auxiliary flue.
- Regenerative system exhaust pipe.

The auxiliary flue temperature is ↑1700°F (650°C) to 2150°F (1175°C) normally. This requires an expensive high temperature probe or a low temperature probe with an eductor system. Measuring in the auxiliary flue provides the most accurate information on the furnace atmosphere. The auxiliary flue temperature will fluctuate based on:

- Percentage of POC that is rejected by the regenerative system.
- Volume of combustible passed from the charge/delac chamber.

The fluctuation in the temperature and volume along with particulate at fluctuating velocities may make the low temperature probe eductor and filter option a good choice for accuracy and longevity.

Locating the O_2 probe in the exhaust pipe of the regenerators answers most of the issues on cost, temperature and maintenance:

- The exhaust temperature is less than 600°F (300°C).
- Low temperature system.
- Installation is direct in the pipe. No eductor required.

Information from this location requires an understanding of the regenerative system operation.

The burners operate with reversal valves on the exhaust and combustion air ports to the regenerator. The valves are designed for tight shut off, but there is some leakage. Generally, a 1%-2% leakage rate of combustion air through the exhaust valve when closed. This adds to the O_2 in the flue gas. Most regenerative systems utilize some cooling air on the fuel tube. The cooling air is constant when firing or exhausting. When exhausting, the cooling air is pulled through the regenerator with the POC. This also adds to the O_2 level in the flue gas. The effect of the two air sources varies with the firing rate of the burner. The cooling air remains constant, but the percentage of leakage to total flow varies with the firing rate of the burners.

To further confuse the issue, the regenerator media operates at a peak of 2100°F (1150°C) which will sustain the oxidation of CO, etc. If there is CO in the POC entering the regenerator, it may combine with the O_2 in the cooling air converting to CO_2 and decreasing the O_2 content. The typical flue gas O_2 is between 4%-6% with the furnace operating at 2%. Add in the variation with CO carry over, an O_2 control set point becomes impossible. Controlling to a set point is difficult to impossible as corrective actions do not result in immediate results. At best, the results will fluctuate. Controlling the O_2 should involve controlling to a set point with a deadband and a time-averaged process variable (PV).

Typical O_2 Envelope (before adjusting)	1 1/2%-4% in flue
	4%-6% in exhaust duct

O_2 PV time average over 10-15 seconds. Actual numbers need to be determined once the system is operational.

Melt Rate and Circulation

The melt rate is dependent on:

1) The temperature of the metal charged into the well.
2) Mass of metal recirculation through the well.
3) Temperature of the recirculated metal.

The key to maximizing metal circulation is a charging practice that does not plug/choke the well reducing the metal flow. The "rule of thumb" is not to exceed a charge rate of 150 Lb/Hr/Ft^2 of well surface area. This varies +/- depending on the scrap configuration/density and temperature.

Assuming pure aluminum:

- Melting Point: 1215°F (658°C)
- Btu/Lb to Melt: 455 Btu/Lb (253 cal/g)

Heat content of scrap @ 600°F (315°C) = 150 Btu/Lb (83 kcal/kg)
Heat content of incoming metal @ 1350°F (732°C) = 500 Btu/Lb (275 kcal/kg)
Heat content of metal returning to the main chamber @ 1250°F (675°C) = 460 Btu/Lb (255 kcal/kg)
Total heat transfer hot to cold = 40 Btu/Lb (22 kcal/kg)
Heat required to melt and bring 1 Pound metal from 600°F (315°C) to 1250°F (675°C) = 310 Btu/Lb (170 kcal/kg)

$$\frac{\text{Lb Recirculated Metal}}{\text{Lb melted}} = \frac{310\ \text{Btu/Lb}}{40} = 7.75\ \text{Lb/Lb}$$

Numbers are rounded off, but this is the best-case condition. There is no accounting for heat loss from the bath surface or wall losses. The actual requirement could easily double to 16 Lb/Lb. A 10,000 Lb/hour melt rate could easily require 160,000 Lb/hour recirculated metal. The well must be sized to ensure the required circulation for the scrap/density and charge rate to transfer the heat.

Convection is the primary mode of heat transfer in the well. The amount of heat transferred is dependent on the differential temperature between the liquid and scrap, velocity of liquid and the total surface area interacted with. Retention time becomes a concern as the surface area to weight ratio of the scrap varies. Low surface area to weight means less surface area to transfer heat and increase time to conduct the energy through the piece. To maintain the melt rate, the heat transfer in the main chamber must be sufficient to reheat the liquid from 1250°F to 1350°F (675°C to 732°C).

Note: 1350°F (732°C) is the minimum. 1400°F (760°C) is feasible.

Heat transfer in the main chamber is primarily radiation:

- Reradiation refractory to metal surface is dominant.
- Retention time of the liquid before returning to the well.
- Metal surface area for transfer of heat.
- Metal depth.

Heat transfer in the main chamber is an extensive subject. The typical gross input and melt rate capability are similar to a well charged melter:

- Melt rate with cold charge: 40 Lb/Hr/Ft^2 (192 kg/m^2) hearth area.
- Melt rate with preheated charge (600°F (315°C) preheat): 50 Lb/Hr/ Ft^2 (240 kg/m^2) hearth area.

Scrap with a higher preheat will increase the melt rate.

Gross input design: 2,000 Btu/Lb/Hr melt rate or 100,000 Btuh/Ft^2 hearth area (268,000 kcal/m^2) whichever is greater.

If the transfer time for the hot metal to the process is lengthy, 120,000 Btu/Ft^2/Hearth (322,000 kCal/m^2) would provide faster recovery after the metal transfer. Gross input should be such that at full melt rate, the burner operates at 80%-85% of the gross input.

Furnace Pressure Control

Two furnace pressure control loops are required.

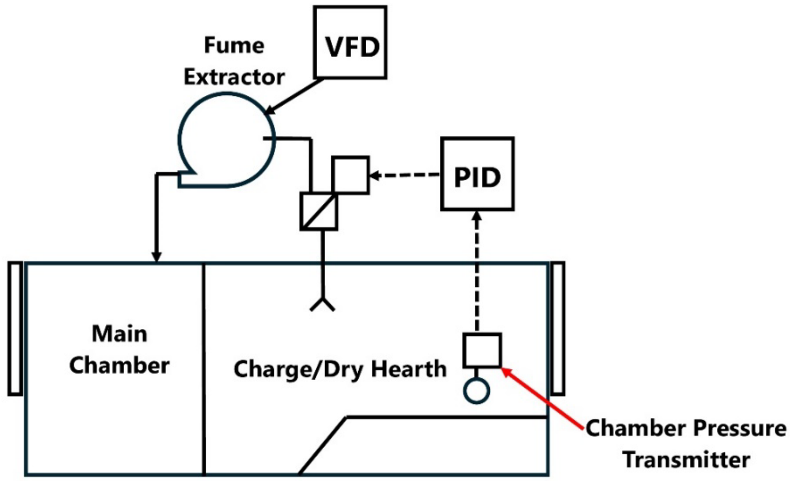
<u>Dry Hearth</u>

The dry hearth chamber pressure is controlled by the fume extraction fan. Typically, the charged door seals tight with mechanical locking devices to minimize tramp air entering the chamber. The fume extraction fan is sized to remove the pounds of volatized fumes from the scrap + POC (products of combustion) from a recirc burner + O_2 from makeup air source used in the process. (Amount of makeup air varies with the type of volatilization process.)

The pressure in the chamber is controlled by the fume extraction fan. The fan is sized for operating at high temperatures, typically, 1200°F (650°C) maximum. The suction pressure/volume/mass are based at the designed operating temperature, 1000°F +/- (540°C). The motor HP (kW) would be sized to these conditions. During cold start and varying operating temperatures, the fan speed needs to be controlled to avoid overloading the motor and uncontrollable exhaust suction pressures. The fans are equipped with VFD's (variable frequency drives) to allow correcting for the different operating conditions and to save energy.

The VFD is very useful to control these issues, but not useful for modulating to control the chamber pressure. PID (modulating) control of a fan/blower speed is not recommended. The motor/impeller inertia does not facilitate reasonable and consistent response times as well as electric issues in the motor and VFD (another subject of discussion). The VFD should be set at the speed required to satisfy the pressure and mass demand based on the operating temperature. As the fluid temperature varies, the operating characteristics of fan/blower vary.

The fan speed should be adjusted in 4 to 6 steps based on operating temperature ranges. The actual chamber pressure control is accomplished with a modulating valve on the inlet to the blower.



MC-7

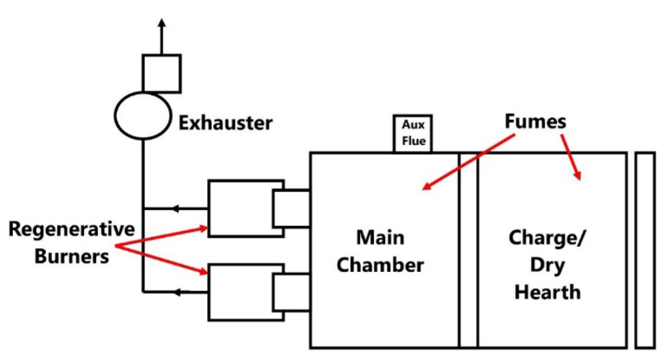
Fluid Temperature	Fan Speed
70°F to 200°F	X
200°F to 500°F	X1
500°F to 800°F	X2
800°F to 1100°F	X3
Typical Only	

Furnace Pressure Set Point -.02″ wc to +.03″ wc
Outside of s.p. range
No adjustment made.
Furnace pressure
P.V. (process variable)
Time averaged over 7 seconds.
Typical design only

MC-7 shows the typical basic set up to control the fume stream transfer and chamber pressure. All parameters need to be field adjustable to accommodate actual operating conditions.

Main Chamber

Controlling the pressure in the main chamber is a bit more complicated. The POC exits the main chamber through the regenerators or the auxiliary flue.



MC-8

In theory, the regenerative system extracts 80% of the POC generated by the operating burner. In most systems, this can vary +/- an additional 10%-15%. Main reasons for the variations:

- Regenerator media plugging with particulate.
- Exhaust system control variations due to exhaust stream temperature variation (exhaust pressure and mass variations).
- Variation occurs every reversal as the exhaust switches from one unit to the other.

The auxiliary flue is sized to extract the rejected POC from the regen system plus the POC from the charge chamber fume stream and air/O_2 added for the oxidation process. The extraction requirements vary due to:

- Variations in regenerative system exhaust.
- Fluctuations in the volume and organic concentration of the fume stream from the charging chamber.
- Volume of makeup air required for oxidizing organics.

Considering all the variables controlling the chamber pressure is a challenge. To reduce the sources of variation, the exhaust rate from the regenerators should be controlled as much as possible. Knowing the exhaust fan/blower characteristics and selection parameters provide the information necessary for control. The exhauster is rated at a rotation speed to move “x” volume at a specific temperature. The volume at “x” temperature = the total mass moved. When the temperature changes, the volume exhausted stays the same, but the mass changes. Knowing the firing rate of the burner, the total mass of POC can be determined. Using the exhauster characteristics, the mass being exhausted can be determined with a reasonable accuracy.

Controlling the mass extracted through the regenerator based on the firing rate of the burners aids in designing a pressure control system with reasonable results. With the regen exhaust under control, the main variable is the fume stream from the charge chamber and the air required for oxidation. The fume stream will vary in volume and content. The volatilization rate of water and organics varies greatly with incoming temperature and chemical makeup.

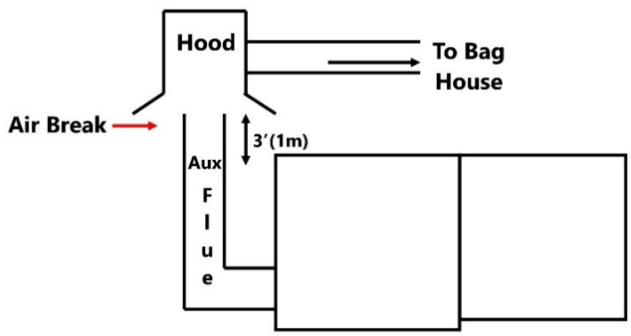
The percentage of organic in the fume stream will determine the air required and has the greatest effect on the chamber pressure swings. Most inorganics will transfer as particulate. Some such as zinc or magnesium may gasify but aluminum, iron, and copper may fluidize but remain as particulate. The greatest effect on pressure will be the expansion of the gases due to the increase in temperature and the oxidation of the organics. Increases in temperature from 1000°F (538°C) to 2150°F (1175°C) increases volume x2 +/-. As the amount of fumes increase so too will the firing rate that is necessary for the main chamber burners to maintain the 2150°F (1175°C) temperature with the regenerator exhaust set.

The primary means of pressure control is controlling the exit volume through the auxiliary flue. Furnace pressure control on a typical regenerative fired furnace is adequate at best. The reversals of the burner causes an upset in chamber pressure every 40-60 seconds. (Regenerative cycling with less than 40 seconds reversals, essentially means there is no control of this variable.)

Couple this with the varying fume flow and chaos may occur. To achieve some stability in the p.v. (process variable), the p.v. raw data is time averaged over a 10 +/- second interval, and then the average number is sent to the control loop. The furnace pressure s.p. (set point) has a dead band, Ex: .05″ wc +/- .02″ wc. As long as the input p.v. is between +.03 wc to -.03″ wc (+9 to -9 Pa), no action is taken. The same control strategy is used in the main chamber.

Note: Actual p.v./s.p. numbers vary with furnace pressure tap locations.

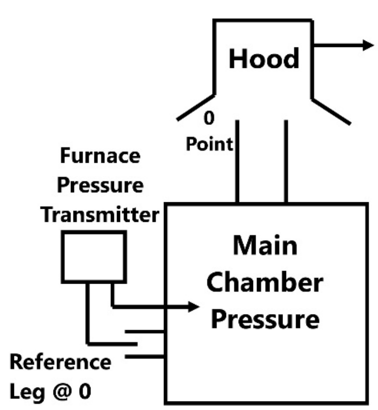
There may be additional factors to consider.



MC-9

The height of the auxiliary flue can be a factor to be considered. MC-9 shows a typical short stack with a collection hood. The height of this stack will have a minimal effect on the control requirements. If the stack was considerably taller, +10′ (3m) or more, above the roof or had a long horizontal run, the fluctuations in natural draft or back pressure as temperatures change may require consideration in control design.

Regenerative systems, in general, operate best with an air break or zero (0) pressure point at the top of the stack/flue. This means the pressure control system sees a constant downstream pressure to create the differential pressure (ΔP) versus.



MC-10

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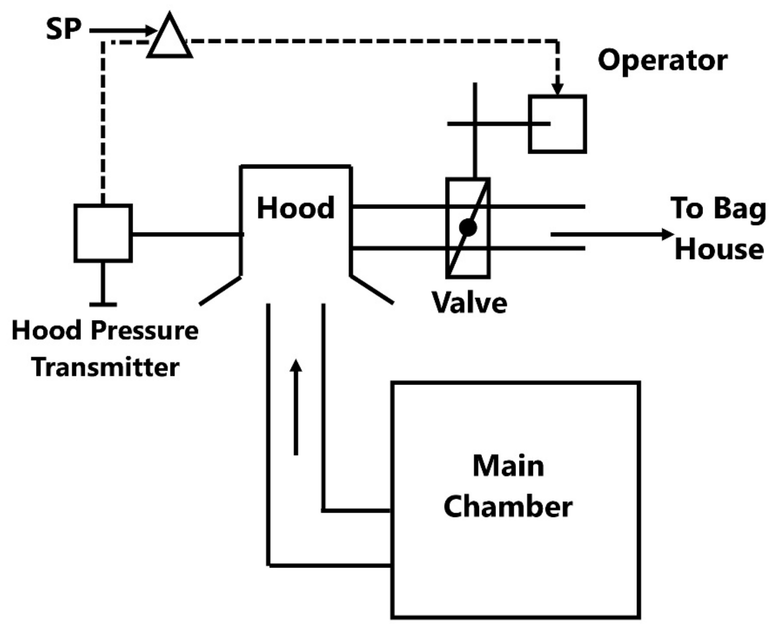
The reference leg of the furnace pressure transmitter and flue exit are equal (within reason) giving a reliable indication of chamber pressure. The air break allows air to be pulled in diluting the fume stream to the bag house. The bag house rarely runs at high temperature and additional cooling is necessary. (Low temperatures allow less expensive hood and ducting materials.) In many instances, the bag house will service more than one furnace. As the furnaces cycle, the volume of gases to the bag house varies. The bag house adjusts to maintain a draft/suction. This adjustment coupled with temperature changes and duct losses causes the negative pressure in the hood to fluctuate. To avoid the hood fluctuations affecting the furnace pressure, a hood pressure control system may be necessary.



MC-11

MC-11 shows a typical hood pressure control system. There is a control valve that is modulated to hold the hood pressure in a negative (-) pressure range. The s.p. and p.v. are set up similar to the s.p. and p.v. for the main chamber operating with an average p.v. and s.p. with dead band.

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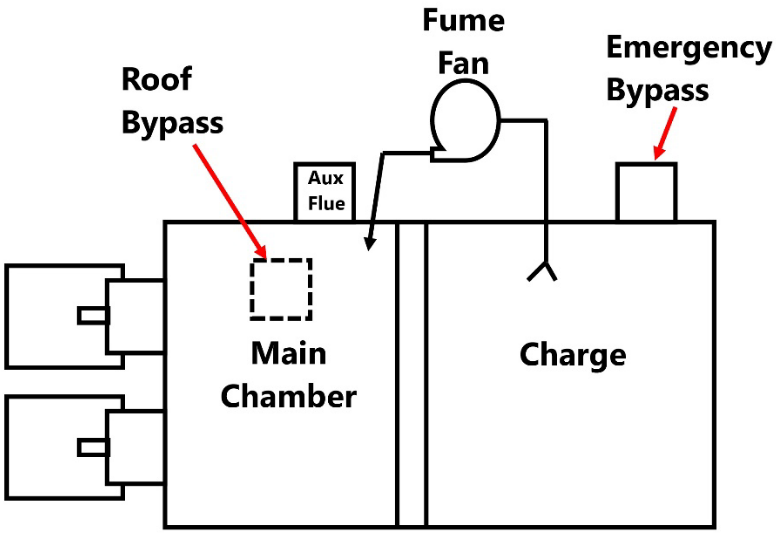
EMERGENCY DUMP/BYPASS STACKS.

Both chambers, main and charge, should have emergency bypass or dump stacks/flues.



MC-12

Emergency stacks are generally located where there is room. It can be a simple roof location or a side stack. In both cases, there is a mechanical damper that fails open under upset conditions.

Charge Chamber Upsets:

- Fume exhaust fan failure.
- Overtemperature
- Burner failure
- Extreme overpressure

Main Chamber Upsets:

- Extreme overpressure
- Combustion system failure
- Auxiliary flue failure

Fluing of POC when emergency bypass/stack opens is determined by user requirements and local codes and site limitations. Requirements for installing a blow-out or rupture panel in the charge chamber are based on local regulations.

ADDITIONAL CONSIDERATIONS

1) Doors need to close tightly to avoid tramp air entering and fumes/POC leaking out. Typically, the doors would have mechanical closing/locking mechanisms.

2) Charging chamber door should have proof of closure and mechanical lock when the door is closed. After a charge is made, the door should be locked in the closed position for “x” period of time. This is to ensure the door is not opened with a subsequent drafting of air into a fume laden chamber. Minimizing a potential uncontrolled ignition.

3) The charging ramp needs to have a slight taper from the door to well. Even at 3 to 3 ½ degree slope, this can make the height from the floor to sill, higher than the norm. This must be taken into consideration when locating the furnace and assessing charging capabilities.

4) Both chambers need to be accessed for drossing and hearth cleaning. The main chamber requires the typical capabilities. The well area of the charging chamber requires a side cleanout door for:
    - Drossing/cleaning
    - Break up of charge material that may “bridge” the well.
    - Flux addition when required.

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