GRADED SpA.

AREA RICERCA & SVILUPPO

IL PROGETTO DI TIROCINIO PER PROGETTARE UN BRUCIATORE

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Introduction

Graded S.p.A. has established itself as a pioneer in the design and management of integrated energy solutions, with a strong focus on research and development (R&D) to drive the ecological transition. Within this framework, **Project POTTERS** (Portable Thermal Treatment for Effective and Regenerative Sludge management) represents a strategic initiative aimed at revolutionizing the management of municipal and industrial wastewater sludge.

Current disposal methods, primarily landfilling and incineration, are increasingly constrained by stringent environmental regulations and high operational costs. Project POTTERS seeks to transform this "waste" into a resource through a pilot thermal drying system that emphasizes portability, energy recovery, and minimal environmental impact.

The thermal drying of sludge is an energy-intensive process that requires precise temperature regulation to ensure product safety and quality. A critical challenge in the development of the POTTERS pilot plant is the generation of a stable, high-volume hot air stream (**5,700 kg/h at 150°C**). While industrial solutions are available, they often involve high capital expenditure (CAPEX) and complex proprietary integration.

Furthermore, the project aims to enhance sustainability by utilizing **Waste Vegetable Oil (WVO)** as a primary fuel source. This introduces technical hurdles regarding fuel viscosity, combustion stability, and the safe mixing of ultra-high-temperature burner fumes (~1500°C) with process air.

Objective

This report, developed during my internship at Graded S.p.A., provides a comprehensive techno-economic evaluation of two distinct pathways for the 200-kW thermal generation system:

1. An Integrated Solution: A stepwise engineering approach to constructing a custom system using standalone universal burners, custom mixing chambers, and digital acquisition tools.

2. An Industrial Turnkey Solution: An analysis of standardized industrial systems, specifically those provided by the ANDRITZ Group, to serve as a benchmark for performance, safety, and digital transformation.

By comparing these two options, this report aims to provide Graded with a clear roadmap for the selection and implementation of the thermal core for the POTTERS pilot plant, balancing immediate investment costs against long-term operational efficiency and data-driven process control.

INTEGRATED SYSTEM

1) Burner
2) Recirculation
3) Preheating System
4) Dryer Exhaust
5) Controller

1. BURNER

To satisfy the thermal requirements of Project POTTERS, a standalone industrial burner must be integrated into the pilot plant's core. The primary objective is to elevate 5,700 kg/h of process air to a target temperature of 150°C. Based on thermodynamic calculations ($Q = \dot{m} \cdot C_p \cdot \Delta T$), a thermal power output of 200 kW is required.

A critical constraint for this selection is the use of Waste Vegetable Oil (WVO) as a sustainable fuel source. WVO combustion inherently occurs at a peak adiabatic flame temperature of approximately 1,500°C. Consequently, the burner must be capable of sustaining high thermal levels while providing the mechanical flexibility for custom air-mixing integration.

For the thermal core of the POTTERS pilot plant, the **BNTET BNW-20** industrial waste oil burner has been selected as the primary standalone "combustion engine." This unit is specifically engineered to handle non-standard, high-viscosity fuels such as **Waste Vegetable Oil (WVO)**.

The BNW-20 provides a modular, "bare" burner configuration, which is essential for our integration strategy. It allows Graded to manually engineer the external preheating and mixing systems.

Model	BNW-20
Heating Power	154-308 kw
Oil Consumption	15-30 kg/h
Inner Matrials	Stainless Steel
Motor Power	0.37kw
Power Supply	1N 220V 50Hz
Control Method	One Stage Automatic
Packing Size(mm)	850x580x440
Weight(Kg)	30

The technical capabilities of the BNW-20 align with the energy balance requirements for heating the process air:

Thermal Power Output

The burner offers a range of **154–308 kW**, which effectively covers the **200-kW** required to elevate the target mass flow of **5,700 kg/h of air** to the process temperature of 150°C.

Fuel Consumption
The unit supports a fuel flow rate of 15–30 kg/h. This matches the calculated requirement of approximately 24 kg/h to reach the 150°C target while allowing for a peak design flow of 30 **kg/h** to handle cold-start transients or increased sludge loads.

Combustion Temperature
The burner produces high-velocity fumes at a thermal level of approximately **1,500°C**. This high-temperature core is critical for ensuring the complete thermal breakdown of waste vegetable oil before the fume.

SCALE FACTOR OF INVESTMENT COST, OPERATING COST & ENERGY YEILDS

Investment Cost

In industrial engineering, the relationship between the capacity of a system V and its associated costs C is defined by the power-law equation:

$$C_2 = C_1 \cdot \left(\frac{V_2}{V_1}\right)^n$$

Where n represents the scale factor. For the POTTERS project, we evaluate three distinct scale factors to justify the transition from a small-scale reference unit **BNW-10** to the pilot-scale **BNW-20**.

Model	BNW-10
Heating Power	61-122 kw
Oil Consumption	6-12 kg/h
Inner Matrials	Stainless Steel
Motor Power	0.18kw
Power Supply	1N 220V 50Hz
Control Method	One Stage Automatic
Packing Size(mm)	550x470x330
Weight(Kg)	16

Specification of BNW-10

The investment cost follows the Six-Tenths Rule logic, driven by the geometric relationship between material requirements and thermal output.

Geometric Proof: The cost of the BNW-20 is primarily determined by the surface area (S) of its stainless-steel components, while its capacity (kW) is determined by its internal volume (V).

Exact Dimensional Data:

BNW-10: $L = 0.55$ m, $r = 0.222$ m $\rightarrow V = 0.085$ m^3, $S = 0.767$ m^2.

BNW-20: $L = 0.85\ m$, $r = 0.285$ m $\rightarrow V = 0.217$ m^3, $S = 1.522$ m^2.

Derivation: By solving the ratio $\frac{1.522}{0.767} = \left(\frac{0.217}{0.085}\right)^n$, we derive an exact investment scale factor of $n_{CAPEX} \approx 0.72$.

The Capacity Gain: Moving from the BNW-10 (0.085 m³) to the BNW-20 (0.21692 m³) is a ratio of **2.55** (a **255%** increase).

The Material Gain: Moving from the BNW-10 surface (0.767 m²) to the BNW-20 surface (1.522 m²) is a ratio of **1.98** (a **198%** increase).

CAPEX (Capital Expenditure).

A 255% increase in capacity results in only a 198% increase in material cost, effectively lowering the CAPEX per kilowatt of thermal power delivered.

CAPEX scale factor $= \frac{\ln(C_2/C_1)}{\ln(Q_2/Q_1)} = 0.72$

Where C_1, C_2 is the cost of burner & Q_1, Q_2 is the capacity of the burner.

SINCE $n < 1$ THE LARGER BURNER COSTS LESS PER kW THAN THE SMALLER ONE.

Operating cost

The operating cost (OPEX) of industrial burners includes **fuel, maintenance, and labour costs**. The scale factor n_{OPEX} (Operational expenditures) indicates how the total operating cost changes with burner capacity.

The formula for the scale factor is:
$$n_{\text{OPEX}} = \frac{\ln(O_2/O_1)}{\ln(Q_2/Q_1)}$$

Where:
O_1, O_2 = total operating costs of the smaller and larger burner
Q_1, Q_2 = capacities (kW) of the burners

BURNER	FUEL CONSUMPTION kg/h	CAPACITY kW
BNW - 10	$6 - 12 \rightarrow$ midpoint 9	$61 - 122 \rightarrow$ midpoint 91.5
BNW - 20	$15 - 30 \rightarrow$ midpoint 22.5	$154 - 308 \rightarrow$ midpoint 231

Assuming operating hours/year = 4000 h/year (typical for industrial use)
Fuel price = €1.5/kg (example)

Fuel Cost

Fuel cost per year = Fuel consumption x hours/year x price/kg
BNW-10: $9 \times 4000 \times 1.5 = 54{,}000€$
BNW-20: $22.5 \times 4000 \times 1.5 = 135{,}000€$

Maintenance Cost

Assuming:
BNW-10 → €2,500/year
BNW-20 → €5,000/year

(Based on parts + service labour, scaled roughly 2× because the larger burner has bigger/more expensive components)

Labour Cost

Assuming:
1 operator can handle either burner, but larger burner may require more attention → scale slightly

BNW-10 → €10,000/year
BNW-20 → €12,000/year

Total OPEX per year

$$O_{\text{total}} = \text{Fuel} + \text{Maintenance} + \text{Labour}$$

BNW-10: 54,000 + 2,500 + 10,000 = 66,500€
BNW-20: 135,000 + 5,000 + 12,000 = 152,000€

Scale Factor

$$n_{\text{OPEX}} = \frac{\ln\left(O_2/O_1\right)}{\ln\left(Q_2/Q_1\right)}$$

$$n_{\text{OPEX}} = 0.827/0.926 \approx 0.893$$

Interpretation

OPEX scale factor ≈ 0.89
Slightly sublinear → economies of scale due to maintenance & labour not increasing as fast as fuel
Fuel dominates (linear), maintenance/labour introduces slight economy

Energy yield

Energy yield E is usually the **annual energy delivered by the burner**, calculated as:

$$E = Q \times \text{Operating hours/year}$$

Where,
Q = thermal output (kW)
Operating hours/year = annual usage

So, it's measured in **kWh/year** or **MWh/year**

Burner	Capacity (kW)	Operating hours/year
BNW-10	91.5 (midpoint)	4000 h
BNW-20	231 (midpoint)	4000 h

$$E_1 = Q_1 \times \text{hours} = 91{,}5 \times 4000 = 366{,}000 \text{ kWh/year}$$
$$E_2 = Q_2 \times \text{hours} = 231 \times 4000 = 924{,}000 \text{ kWh/year}$$

Energy Yield Scale Factor

$$n_{\text{energy}} = \frac{\ln(E_2/E_1)}{\ln(Q_2/Q_1)}$$

$$n_{\text{energy}} = 0{,}926/0{,}926 \approx 1{,}0$$

Where E_1, E_2 = energy yields, Q_1, Q_2 = capacities

Interpretation

Energy yield scale factor = 1.0
Energy delivered per year is directly proportional to capacity, assuming same operating hours

2. MIXING OF EXHAUST AND FRESH/AMBIENT AIR

The implementation of a recirculation loop is technically mandatory because the WVO burner produces combustion fumes at an extreme temperature of 1.500°C, which would cause immediate structural failure of the dryer and spontaneous ignition of the sludge if applied directly. To safely reach the target operating temperature of 150°C, the system utilizes the recirculated exhaust air as a high-volume "thermal quenching" medium. By transporting a massive volume of cooler air to mix with the high-intensity flame, the system effectively dilutes the burner energy at a 1:14 ratio, absorbing the excess heat and homogenizing the air stream into a safe, controlled 150°C flow. This process not only protects the structural integrity of the equipment but also recovers significant thermal energy, ensuring the 1.500°C fumes are tempered into a usable drying medium without wasting fuel.

As air dries sludge, its humidity increases. If the temperature drops below 70°C–75°C (the dew point), the water vapor will condense back into liquid, creating acidic "mud" in the exhaust ducts. 85°C is high enough to keep moisture in a gaseous state but low enough to ensure the air has surrendered the maximum possible energy to the drying process.

If 100% of the air recirculated, the system would quickly become saturated (100% humidity) and stop drying. Introducing 50% fresh air of the total secondary air ensures a constant supply of dry air to absorb moisture and provides the oxygen required for the WVO burner to maintain a clean 1,500°C flame.

To maintain these exact parameters a thermocouple at the dryer inlet must modulate the WVO burner fuel pump. If the temperature drops below 150°C, the burner increases fuel flow (m_h increases), Manual or motorized dampers on the Fresh Air and Recirculation ducts should be locked in a 1:1 position & if the exhaust temperature falls below 85°C, the operator must reduce the sludge feed rate.

The mixing box is equipped with two high-precision, heavy-duty modulating dampers: the Fresh Air Damper (FAD) and the Recirculated Air Damper (RAD). These components are integrated into the PLC (Programmable Logic Controller) to manage the following Cold start and recirculation process.

Mixing

The intense energy of the burner fumes is mixed by a much larger volume of lower-temperature secondary air, absorbing and distributing the energy to reach the homogenized 150°C setpoint.

During initial startup, the dryer is cold, and no recirculated air is available. The mixing system must rely solely on 20°C fresh ambient air for quenching. This necessitates a temporary increase in burner fuel consumption to compensate for the lower initial air temperature.

Mathematical Modelling (Thermal Balance)
The exact mass of 1.500°C air required is derived from the Fundamental Heat Balance Equation

Where,
$m_{total}^{\cdot}$: Total System Mass Flow (5.700 kg/h).
m_{hc}: Mass Flow Rate of Hot Burner Fumes at cold start.
m_{hR}: Mass Flow Rate of Hot Burner Fumes at Recirculation.
T_h: Combustion Flame Temperature (1.500°C).
T_{set}: Target Dryer Inlet Temperature (150°C).
T_{ex}: Exhaust Temperature (Target: 85°C).
T_{AvgR}: Weighted Intake Temperature of ambient & recirculated air (52,5°C).
$T_{ambient}$: Ambient air Temperature (20°C)
$\dot{m}$ ($MassFlowRate$): 5.700 kg/h ÷ 3.600 = 1,583 kg/s
C_p ($Specific Heat of Air$): 1,006 kJ/kg · °C
LHV (kJ/kg) = 37.000 kJ/kg
$\eta = efficiency\ of\ boiler$ 90%
$m_{fuelc}^{\cdot}$ = Fuel consumption at cold Start
$m_{fuelR}^{\cdot}$ = Fuel consumption at recirculation

COLD START

$$(m_{hc} \cdot T_h) + ((m_{total} - m_{hc}) \cdot T_{ambient}) = (m_{total} \cdot T_{final})$$

$$(m_{hc} \cdot 1500) + ((5700 - m_{hc}) \cdot 20) = (5700 \cdot 150)$$

$$m_{hc} = 500{,}67 \text{ kg/h}$$

Power

$$Q = \dot{m} \cdot C_p \cdot \Delta T$$

$$Q = \dot{m} \cdot C_p \cdot (T_{set} - T_{ambient})$$

$$Q = 207 \ kW$$

Temperature

$$T_{final} = \frac{(m_{hc} \cdot T_h) + \{(m_{total} - m_{hc}) \cdot T_{ambient})\}}{m_{total}}$$

$$T_{final} = 150°C$$

Fuel consumption

$$\dot{m}_{fuelc} = \frac{Q \cdot 3600}{\text{LHV} \cdot (\eta)}$$

$$\dot{m}_{fuelc} = 21{,}84 \ kg/h$$

RECIRCULATION OF EXHAUST AIR

$$(m_{hR} \cdot T_h) + ((\dot{m}_{total} - m_{hR}) \cdot T_{base}) = \dot{m}_{total} \cdot T_{set}$$

$$(m_{hR} \cdot 1500) + ((5700 - m_{hR}) \cdot 52{,}5) = 5700 \cdot 150$$

$$1447{,}5 \cdot m_{hR} = 555.750$$

$$(m_{hR}): 383{,}9 \text{ kg/h}$$

Power

$$Q = \dot{m} \cdot C_p \cdot \Delta T$$

$$Q = \dot{m} \cdot C_p \cdot (T_{set} - T_{avgR})$$

$$Q = 155{,}3 \ kW$$

Temperature

$$T_{final} = \frac{(m_{hR} \cdot T_h) + \{(m_{total} - m_{hR}) \cdot T_{avgR})\}}{m_{total}}$$

$$T_{final} = 150{,}01°C$$

Fuel consumption

$$\dot{m}_{fuelR} = \frac{Q \cdot 3600}{LHV \cdot (\eta)}$$

$$\dot{m}_{fuelR} = 16{,}79 \; kg/h$$

Mass dilution Ratio

$$\frac{\dot{m}_{total} - m_{hR}}{m_{hR}}$$

At the calculated steady state, the system maintains a ratio of approximately 1:14. For every 1 kg of high-temperature gas, 14 kg of moderate-temperature intake air acts as a thermal heat sink.

Water removal rate

$$\dot{m}_{water} = \frac{Q_{evap}}{h_{fg}}$$

$$\dot{m}_{water} = 165{,}08 \; kg/h$$

Where,
Q_{evap} is the available evaporation energy = 1,583 kg/s · 1,006 · (150 - 85) = 103,5 kW
h_{fg} is the latent heat of vaporization (2.257 kJ/kg)

$$\dot{m}_{water} = 165{,}08 \; kg/h$$

3. MIXING SYSTEM

The thermal system is designed to provide a stable and efficient heat source for municipal sludge drying by precisely managing the transition from high-intensity combustion to a safe process temperature. At the core of the operation, a high-performance burner generates a concentrated flame that is contained within a refractory-lined chamber to ensure structural integrity and thermal efficiency. This heat is then meticulously blended with a high-volume air stream of 5,700 kg/h, which acts as a dilution medium to achieve a consistent 150°C output. By integrating a recirculation loop that recovers residual heat from the dryer exhaust, the system significantly reduces fuel consumption while maintaining the precise atmospheric conditions necessary for effective moisture removal.

Refractory lining & HGG combustion chamber

The Hot Gas Generator (HGG) and its Refractory Lining function is a single, integrated thermal unit designed to manage the transition from extreme combustion to stable process heating. While the HGG provides the structural steel housing and pressure vessel capabilities, the refractory lining provides the essential thermal shield that makes the operation possible. This combined assembly is utilized to safely host the 1,500°C flame generated by the BNW20 burner. By applying a high-alumina castable refractory to the interior of the steel HGG, the system creates a "thermal buffer", This allows the core of the chamber to remain at intense temperatures for optimal waste oil combustion while the external steel shell remains at a safe, manageable temperature for structural integrity and operator safety.

The refractory lining absorbs and reradiates heat back into the flame zone. This creates an effect that is crucial for burning waste cooking oil, ensuring that droplets are fully gasified and preventing the formation of unburnt residues that could contaminate the sludge.

The integrated chamber provides the necessary volume for the 5,700 kg/h dilution air to mix with the combustion gases. This ensures that by the time the air reaches the dryer, it has been successfully quenched from 1,500°C to a homogenous 150°C, this happens after the dilution of diluted exhaust air of dryer & ambient air in the HGG combustion chamber.
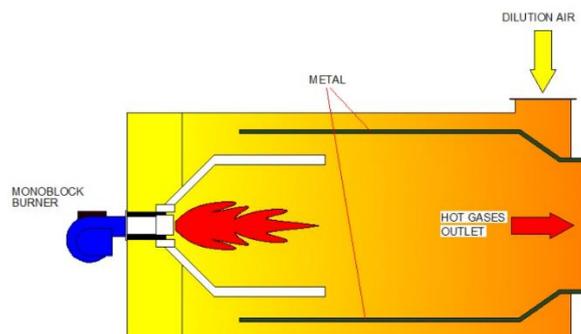
Size of the combustion chamber

Burner power of 155.3 kW after the dilution and the requirement to process 5,700 kg/h of air,

Air Volume Flow (A_f)

At 150°C, the density of air (ρ) is approximately 0.834 kg/m^3

$$A_f = \frac{\text{Mass Flow}}{\rho} = \frac{5.700 \text{ kg/h}}{0,834 \text{ kg/m}^3} = 6.834,5 \ m^3/ \text{ h} \approx 1,90 \ m^3/s$$

Chamber Volume (V)

For industrial HGGs, a Residence Time (τ) of 0,4 s is the engineering standard to ensure the 1,500°C flame and dilution air mix thoroughly into a homogenous 150°C stream.

$$V = Q \text{ X } (\tau) = 1,90 \ m^3/s \cdot 0,4 \text{ s} = 0,76 \ m^3$$

Volumetric Heat Release Rate

The q_v is the ratio of the burner's thermal power to the volume of the chamber. To find the exact value, we first determine the chamber volume V required to allow the 5.700 kg/h of air enough time to mix and stabilize at 150°C.

$$q_v = \frac{power}{volume} = 204,4 \text{ kW/ } m^3$$

Dimensions for the HGG Chamber

To maintain the required volume ($0,76 \text{ } m^3$) while ensuring the BNW20 burner flame has enough clearance to avoid damaging the refractory walls:

The internal diameter (D) should be roughly 1,4 to 1,5 times the flame diameter.

$$D = d_f \times 1,45$$

$$D = 480 \text{ mm} \times 1,45 \approx 700 \text{ mm}$$

Chamber Length (L):

$$L = \frac{V}{\pi \times r^2} = \frac{0,76}{3,1415 \times 0,35^2} \approx 1,97 \text{ m (Rounded to 2,0 m for construction)}.$$

Components required

1. Engineered slots or holes in the inner lining that allow the Flowing Air to enter the chamber at high velocity to cool the flame.

2. Flame Scanner (UV Cell): An optical sensor that sees the flame. If the flame goes out, it triggers an immediate fuel shut off.

3. High-Limit Thermocouple (Type K): A heavy-duty temperature sensor at the HGG outlet. If the temperature exceeds 150°C significantly, it shuts down the burner to protect the dryer.

4. Explosion Relief Door (Venting): A spring-loaded or burst disc door designed to release pressure safely in the event of an ignition delay or pressure surge.

5. Differential Pressure Gauge: To monitor the resistance across the combustion chamber.

6. Air Inlet Flange: Where the ducting from the blowing air attaches (400mm diameter).

7. Hot Gas Outlet Flange: The connection leading to the sludge dryer (400mm diameter).

8. Inspection Port / Peep Sight: A quartz-glass window allowing the operator to view the flame shape and colour without opening the chamber.

9. Scavenge/Drain Port: At the bottom, to remove any unburnt oil or residue during maintenance.

10. Burner Mounting Plate: A heavy, machined steel plate at the front of the chamber with a specific bolt pattern to hold BNW20 burner securely in place.

11. Duc to dryer: Ø 400 mm Stainless Steel (SS304), At 150℃ stainless stays clean.

12. High-Temp Insulation: 50 mm to 100 mm Rockwool with Aluminium cladding.

13. Expansion Joint (Metallic Bellows): Bellows that allows the pipe to grow in length as it heats from room temperature (cold start) to 150 ℃.

14. Temperature Transmitter (RTD/PT100): Placed right before the dryer inlet to confirm the air hasn't cooled down.

15. Inlet Diffuser: A transition piece that expands the Ø 400 mm pipe to the width of the dryer bed to spread the air evenly.

16. Safety High-Limit Switch: To shuts down the burner if this duct hits a more temperature (e.g., >200 ℃).

Mixing Plenum

The Mixing Plenum serves as the central atmospheric junction for the system, acting as a specialized pressure-stabilizing chamber where multiple air streams are unified. Its primary function is thermal homogenization. By providing a large internal volume, the plenum forces the high-velocity intake air and the warm recirculated exhaust gases to slow down and blend thoroughly. This prevents a condition where layers of air at different temperatures remain separate which could otherwise cause unstable combustion or cold shock the burner's refractory lining.

Beyond stabilization, the plenum is the engine of the system's heat recovery strategy. By pulling warm air back from the dryer exhaust, it pre-heats the intake stream, significantly reducing the temperature gap the burner must close. This "thermal recycling" minimizes the fuel consumption of the **BNW20 burner**, making the sludge drying process more energy efficient. Crucially, this unified air mass acts as the primary cooling medium for the system; once this mixed air is pushed into the HGG, it surrounds the intense 1,500°C flame, quenching and reducing the temperature down to the safe, operational target of 150°C required for the dryer.

Mixing plenum size

The size of the plenum is determined by the Volumetric Flow Rate (Q) and the Target Velocity (V).

Volume Flow (V_f)

We must size the box for the air when it is at its hottest/lightest (largest volume).

$$(V_f): \frac{\dot{m}}{\rho}$$

Mass Flow $(\dot{m})$: 5.700 kg/h = 1,583 kg/s

Assumed Recirculation Temp (T): 80°C (353,15 K)

Air Density (ρ) at 80°C:

$$(\rho) = \frac{P}{R \cdot T} = \frac{101325}{287,05 \cdot 353,15} \approx 1,00 \text{ kg}/m^3$$

$$(V_f): \frac{\dot{m}}{\rho} = \frac{1,583 \text{ kg/s}}{1,00 \text{ kg}/m^3} = 1,583 \, m^3/s$$

Cross-Sectional Area (A)

The plenum dimensions were derived using the Velocity Limitation Method. A design velocity of 4,0 m/s was specified to ensure a Reynolds Number $(Re) > 100,000$, guaranteeing fully turbulent flow for optimal thermal mixing of ambient and recirculated air.

$$A = \frac{V_f}{v} = \frac{1,583}{4} = 0,396 \, m^3$$

Dimensions

Width/Height: $\sqrt{0,396} = 0,629 \text{ m} \rightarrow 630 \text{ m}$

Length (L): The plenum length was specified as (1,75 × Side Length) to establish an adequate mixing development zone.

L = 630 · 1,75 = 1.102,5 mm → 1.100 mm

To guarantee total thermal homogenization, the mixing plenum features internal **Static Mixing Vanes (SS304)**. These vanes are engineered to induce high-frequency micro-turbulence, ensuring that the ambient and recirculated air streams achieve a uniform temperature profile within the 1,100 mm development length.

Components Required

1. External Stiffeners: Angle iron ribs welded to the exterior to prevent wall vibration (drumming) under the suction of the fan.

2. Thermal Insulation: 50 mm thick Mineral Wool (density 80 kg/m³) to prevent energy loss and external sweating.

3. Outer Cladding: A 1,0 mm thick aluminium or SS304 sheet to protect the insulation.

4. Ambient Air Damper: An Opposed-Blade Damper for fresh air intake.

5. Recirculation Air Damper: A High-Temperature Stainless Steel Damper for the warm exhaust air from the dryer.

6. Electric Modulating Actuators: Two industrial actuators (e.g., Belimo or Siemens) that accept a 4–20mA signal from the PLC to precisely blend the air volumes.

7. Static Mixing Vanes (Baffles): A set of V-shaped Chevron vanes welded inside the chamber. These shred the two air streams to ensure a uniform temperature of 52,5℃ before the air hits the fan.

8. Mesh: A stainless-steel wire mesh over the ambient intake to prevent debris from being sucked into the system.

9. Thermowell & Sensor: A 1/2" NPT port for a PT100 (RTD) probe to monitor the mixed air temperature.

10. Differential Pressure Taps: Two small ports for a DP transmitter to monitor filter/damper health.
Inspection Manway: A gasketed airtight door for internal cleaning of sludge dust.

11. Condensate Drain: A 1" NPT socket at the lowest point to drain any water that condenses during system startup.

12. Sight Glass: A small quartz window to visually inspect the internal mixing action.

13. Inlet Flanges: Standard angle-iron flanges for connecting the ductwork from the dryer and the ambient air.

14. Flexible Fan Connector: Used at the outlet to isolate the mixing plenum from the vibration of the secondary blower.

15. Duct: Ø 400 mm Stainless Steel (SS304), The air is approximately 85℃ and nearly 100% saturated with water.

16. Dust Cyclone / Spark Arrestor: A mechanical separator that spins the air to drop heavy sludge particles into a bin before they reach the fan.

17. Clean-out Hatches (Portals): Bolted gasketed doors, Sludge dust is sticky; so, a worker can reach in and scrape the pipes clean once a month. If you don't, the pipes will eventually get clogged.

18. Condensate Drain Points: 1" NPT valves at every low point in the pipe. As the air cools, "sludge water" will rain out inside the pipe.

19. Sloped Installation: The entire pipe run should be tilted ($1° - 2°$ degrees) toward the drains so water doesn't pool in the bottom.

20. Humidity/Dewpoint Sensor: To monitor how much moisture is being pulled out of the sludge.

Air blowing fan

The Air Blowing fan is the primary mechanical driver of the thermal circuit, responsible for moving the process air mass of 5.700 kg/h. This high-performance centrifugal forced-draft fan performs two vital roles: it creates the necessary suction to pull a blend of ambient and recirculated air from the Mixing Plenum and provides the static pressure required to "push" that air through the HGG combustion chamber and into the resistance of the sludge dryer bed.

The air blower is specified as a Direct Drive arrangement, where the backward-curved impeller is mounted directly onto the electric motor shaft. This configuration eliminates the transmission losses (typically 5–10%) associated with belt-driven systems, by removing pulleys and belts, the system benefit from a significantly reduced maintenance profile, increased mechanical reliability, and a smaller equipment footprint. Precise flow control is achieved electronically via the VFD (Variable frequency drive), removing the need for physical pulley adjustments.

Components Required

1. The VFD & Control System

A Variable Frequency Drive (VFD) is an electronic power conversion device/ controller used to regulate the speed and torque of an AC induction motor by varying the frequency and voltage of the power supplied. The inclusion of a VFD ensures maximum energy efficiency by allowing the fan to operate only at the speed required by the process.

2. High-temperature fabric connector (Plenum → Fan), to reduce vibration. The connection from the Mixing Plenum to the Fan Inlet consists of $\emptyset$ 400 mm SS304 ducting to bridge the physical distance. A High-Temperature Flexible Sleeve is installed at the final interface to provide mechanical isolation, preventing the transmission of fan vibration to the Plenum structure and accommodating thermal expansion of the duct run.

3. Discharge Side Flexible Connector: Reinforced high-pressure flexible joint (Fan → Duct).

4. Square-to-Round Transition Adapter: SS304 adapter to match the fan outlet to the $\emptyset$ 400 mm pipe.

5. Backdraught Damper (Check Valve): A mechanical flap that prevents heat from the HGG from flowing back into the fan if it stops.

6. Mating Flange Kits: SS304 rings with high-temperature silicone gaskets and Grade 8,8 bolts.

7. Differential Pressure Taps: Small ports on the inlet and outlet to measure if the fan is performing correctly.

8. Motor Thermistors: Internal heat sensors in the motor connected to the VFD to prevent burnout.

9. Safety Guards: Zinc-plated mesh covers for the motor shaft and cooling fan.

10. Duct Supports: Heavy-duty "U-bolts" and "C-channel" hangers to hold the Ø 400 mm pipes so the fan doesn't have to carry the weight of the ducting.

Schematic diagram