Gasification in the filtration combustion mode for disposal of medical waste with heat generation

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Abstract. The gasification of medical waste (MW) in a counterflow updraft gasifier with a partial recycle of the generator gas to the combustion zone is considered as applied for MW disposal with a heat generation. The temperature regimes and material flows are assessed for a typical model MW composition with a humidity varied from 0 to 40 wt.%. A procedure for control of the process for varied MW composition is proposed. For a given MW composition and flowrate, the combustion temperature can be controlled to prescribed value 900°C via control of the flowrates of air and recycled generator gas. Throughout the studied humidity range the generator gas is combustible and can provide heat generation on the aftercombustion stage. The method promises an efficient and energy sustainable MW disposal.

1 Introduction

The medical waste (MW) makes a small fraction of the total municipal waste, but MW management is an important issue. According to World Health Organization classification [1-3] MW falls in the following categories:
- Infectious waste: waste contaminated with blood and other bodily fluids, cultures and stocks of infectious agents from laboratory work, or waste from patients with infections;
- Pathological waste: human tissues, organs or fluids, body parts and contaminated animal carcasses;
- Sharps waste: syringes, needles, disposable scalpels and blades, etc.;
- Chemical waste solvents and reagents, disinfectants, sterilants and heavy metals contained in medical devices (mercury in broken thermometers) and batteries;
- Pharmaceutical waste: expired, unused and contaminated drugs and vaccines;
- Cytotoxic waste: waste containing substances with genotoxic properties (highly hazardous mutagenic, teratogenic or carcinogenic substances), such as cytotoxic drugs used in cancer treatment and their metabolites;
- Radioactive waste: such as products contaminated by radionuclides including radioactive diagnostic material or radiotherapeutic materials;
- Non-hazardous or general waste: waste that does not pose any particular biological, chemical, radioactive or physical hazard.

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The WHO policy paper [2] suggests that until countries in transition and developing countries have access to healthcare waste management options, which are safer for the environment and health, incineration may be an acceptable response when used appropriately.

The disposal of MW must reduce its mass and volume for safe burial, while preventing a possible spread of pathogens and environmental pollution.

Present practices of MW management in Russia are far from satisfactory [4] so the development of safe and efficient practices for MW disposal is a topical issue.

The MW caloric value can be recovered for heat and/or power generation once the sanitary and environment protection norms are met. An additional to the general environmental problems inherent in municipal waste to energy processes, a difficulty in the disposal of MW is the potential epidemiological danger. Therefore, MW should be separated from the general flow of municipal waste and sterilized to eliminate potential pathogens.

Recently, the problem of MW treatment has escalated worldwide due to the COVID-19 pandemic. It was proposed to coininerate the increased MW flows with the general solid municipal waste [5] to use MW as a fuel. Various ways for MW sterilization were assessed in [6] and it was concluded that chlorine treatment and incineration are preferable. Coincineration was also considered the optimal way for MW disposal due to the caloric value of waste used for power generation [7]. A comparison of various methods for thermochemical conversion of COVID-19-related medical wastes [8] also brings the authors to a conclusion that gasification and pyrolysis are promising in terms of energy efficiency and environmental impact.

The MW disposal must unconditionally exclude spread of the pathogens. This requires:
- reducing contact of the personnel with the (potentially) infected MW;
- containment of infected MW with the minimum possibility of spill;
- thermal sterilization preferably prior to any relocation of MW.

These criteria are strongly in favor of the on-site disposal.

Leaving apart the poisonous (mercury- or arsenic-containing) and radioactive MWs, comprising a small part of MW, whose disposal is dictated by their contamination, consider the disposal of major part of MW. Incineration provides a sterilization and a strong bulk reduction and also a way to generate heat and/or power. Primary concern with the small-scale (onsite) incineration is the environmental pollution, specifically with polychlorinated p-dibenzodioxins and p-dibenzofurans (PCDD/F). The waste pyrolysis/gasification are known to provide alternatives to direct incineration, drastically improving the environmental performance of the process [8 - 10].

We assess the prospects of the gasification technology proposed in [11] – if this technology can provide means for safe and economic disposal of MW with a heat generation.

2 Description of the technology

The method proposed in [11] is another version of the counterflow (updraft) gasification process with a solid granular heat carrier as described in [10].

The schematic diagram of the process is shown in Fig. 1. Fuel charge F - waste with the addition of chemically inert ceramic balls (which act as a solid heat carrier, serve mechanically to secure gradual descent of the fuel charge and ensure the gas permeability of the charge) is loaded into the vertical shaft reactor 1 through the loading device 2 equipped with a gas tight seal. The level of the fuel charge within the reactor is maintained constant using a level sensor 8. In the upper part of the reactor there is a gas outlet 3 through which combustible gas G is withdrawn. The fuel mixture in the reactor descends under its own weight. The mixture is heated by the ascending gas flow, while the fuel dries and pyrolyzes in oxygen-free environment with the formation of pyrolysis gases and char. The carbonized
fuel enters the combustion zone at the level of the combustible gas supply 9, made in the form of tuyeres 13 united by a collector and evenly distributed around the circumference. In the combustion zone at the level of fuel gas supply 9, the char and the combustible gas supplied via tuyeres 13 react with air X, which is supplied through inlet 4 in the lower part of the reactor 1. The air is supplied in oxygen-deficient condition with respect to the fuel. The air, as it rises to the combustion zone, heats up, while cooling the non-combustible material (ceramic balls mixed with the fuel ash). The operation mode of the reactor should be controlled in such a way that the temperature in the combustion zone does not exceed ~900°C. Since the oxygen supply is deficient with respect to the fuel, the gaseous products make a combustible gas containing hydrogen and carbon monoxide. Combustible gas G (it includes both gaseous products coming from the gasification/combustion zone and water vapor and pyrolysis products formed during heating and pyrolysis of the fuel) is partially withdrawn through outlet 11. This gas flow is blown by fan 12 through gas duct 10 into the middle part of the reactor through collector 9 and tuyeres 13. The temperature in the reactor is continuously measured by sensors 7 and the supply of combustible gas G to various tuyeres is regulated using dampers. The solid combustion products formed during char gasification (ash) with the ceramic balls are discharged from the reactor using rotating grate 5 through a gas-tight gate 6. Upon discharging from the reactor, the ceramic balls substantially cooled with the air flow are mechanically separated from the ashes and directed for repeated mixing with the fresh fuel.

**Fig. 1.** A gasifier according to [11] (Schematic). 1 - Reactor; 2 – Charging gate; 3 - Gas outlet; 4 - Air inlet; 5 - Grate; 6 - Discharging gate; 7 – Temperature sensors; 8 – Level sensor; 9 - Gas collector; 10 - Gas duct; 11 – Recycle outlet; 12 - Fan; 13 -Tuyers. F is fuel (mixed with ceramic balls); X is air; G is generator gas; A is ash.
The main difference between this process and the one previously considered in [10] is the recycle of the combustible gas to the combustion zone. This stabilizes the combustion zone in the reactor (important for gasification of inhomogeneous fuel). The supply of the humid generator gas also eliminates the need to humidify the air to control the combustion temperature. The tars contained in the gas recycled to the combustion zone are converted to hydrogen and carbon monoxide, thus reducing the tar content in the generator gas directed to the aftercombustion stage; this facilitates the combustion of the gas in a burner of a heat-generating unit.

The process as described above promises some advantages specifically for incineration of MW with heat generation. Further we assess if the desired gasification regime is attainable for typical MW composition and how this regime can be controlled for varied MW composition.

### 3 Assessment of the gasification regimes

#### 3.1. The material parameters

The reactor throughput in the gross mass of MW, including moisture and the inorganic components was chosen as a reference value in the calculations. The dry mass of MW according to [12] comprises textiles (25 wt.%), paper (20%), plastics (15%), cotton (11%), plaster (10%), food waste (6%), metals (5%), rubber (3%), glass (2%), desinfectants (2%), and biological wastes (1%). In calculations, the dry matter of MW was considered as a mixture of 20% polypropylene to represent plastics and rubber and 63% cellulose as a model for combustible matter of paper, textiles, and food waste. These are the two largest morphological groups of MW. Other components can be neglected in the thermal calculation. The remaining 17% are non-combustibles (ashes). The mass proportions are chosen to bring the lower calorific value of the model mixture, 23.3 MJ/kg, to that of MW.

For real MW its humidity widely varies In the calculations it was varied to assess humidity effect on the process.

General requirement for a gasification process is a higher energy efficiency as this improves the quality of the combustible gas as a fuel and enhances power generation on the aftercombustion stage [9, 13].

The control of the process must satisfy the technological restrictions on the process temperatures:

1) The temperature in the combustion zone should be the maximum allowable. This provides a high reactor throughput and higher quality of the fuel gas (more carbon monoxide and hydrogen). The maximum temperature in the reactor is limited by the need to prevent ash melting. The substantial fraction of low-melting glass in MW restricts the combustion temperature by ~900°C.

2) The temperature of at the reactor outlet must not be lower than the gas dew point. In the calculations this limit was set to 100°C to provide some safety margin.

The calculations were performed for an established operation of the reactor with a prescribed flowrate and composition of MW. The 900°C temperature in the combustion zone was assumed. The calculated control parameters were the air flowrate and the fraction of the recirculated generator gas.

The flowrate of the solid incombustibles (the sum of the ashes and ceramic balls) is an additional control parameter. The process within the combustion/gasification zone is basically conversion of pyrolysis tars to syngas by partial oxidation in a moving bed of the granular heat carrier [15]. Therefore, the flowrate of the solid incombustibles was adjusted to provide the equivalence of the average heat capacity of the solids’ flow to that of the air flow. This secures a perfect heat recuperation to preheat the air flow.
The humidity of the waste in the calculations was varied from 0 to 40 wt.% to determine how the major control parameters – the air flow and the recycle rate of generator gas – should be adjusted to provide the desired regime of the process.

3.2. Zone-by-zone material and energy balance

The process within the reactor is considered under the following assumptions:
- The process is established with constant flowrates and temperatures;
- The reactor is heat insulated, so lateral heat loss is negligible;
- The reactor height provides sufficient heat exchange between the gas flow and that of solids.

Notations.
\( T \) – temperature; \( T_0, T_c, T_g \) – respectively, initial (room) temperature, combustion temperature, and that of the generator gas [K];
\( M_f, M_m, M_a \) - mass flowrates of combustible matter, moisture, and ash in the fuel [kg/s];
Further \( M_f + M_m + M_a = 1 \), the calculation is performed for 1 kg/s MW flowrate;
\( M_c, M_p, m_c, m_m, m_a \) - mass flowrates of char, pyrolysis gas; water vapor in pyrolysis gas; carbon, hydrogen, and oxygen (as chemical elements) in the pyrolysis gas (all components except steam) [kg/s];
\( M_{n}, M_{o} \) - mass flowrates of nitrogen and oxygen of the air [kg/s];
\( \mu_n, \mu_m, \mu_h, \mu_d \) - mass flowrates of nitrogen, steam, hydrogen, carbon monoxide and dioxide as constituents of the synthesis gas [kg/s];
\( H_j(T) \) (j = w, h, m, d, n, i=a, o, p) – mass-specific enthalpies of species [J/kg];
\( H_j(T) = H_j^0 + \sigma_j*(T-T_0) \), \( H_j^0 \) is standard enthalpy of formation, \( \sigma_j \) is specific heat capacity (assumed constant for all species);
\( K = (44*2)/(28*18)*\kappa(T_c) \); \( \kappa \) - equilibrium constant [ND];
\( K_c, k_w, k_h, k_c, k_o \) - mass yields of char, steam, hydrogen, carbon, and oxygen (as chemical elements in the pyrolysis products) per organic mass of MW [ND];
\( Q_w \) – evaporation heat for water [J/kg];
\( Q_p \) – enthalpy of the pyrolysis reaction [J/kg];
\( Q_p = H_p^0 - H_i^0 \) (water in pyrolysis gas is vaporous);
\( N \) – the mass ratio of nitrogen and argon sum to oxygen in air [ND].

Subscripts
\( j = w, h, m, d, n, i, a, o, p \) and \( p \) refer to water, hydrogen, carbon mono- and dioxide, nitrogen, ceramic balls+ ash, oxygen, and pyrolysis gas, respectively.

The calculation was carried out by zones following the MW descent within the reactor (Fig. 1), 1) Drying and pyrolysis zone, from the charging gate to the combustion zone in the middle part of the reactor. Here the fuel (MW and ceramic balls) is heated by the hot syngas from the combustion zone, dried and pyrolyzed to yield pyrolysis gases and char; 2) Combustion zone, where the air reacts with the char and recycled generator gas to yield syngas; 3) Cooling zone, down from the middle of the reactor. Here the solid residue (ceramic balls and ashes) cools down while lending its sensible heat to the ascending air flow.

3.2.1. Drying and pyrolysis zone.

The room-temperature MW and ceramic balls are supplied to this zone from above. The upward flow of hot syngas from the combustion zone heats the descending fuel. The MW is
dried and further pyrolyzed. The steam released in drying and the pyrolysis gases mix with the syngas to form the generator gas.

The material balance for the D&P zone relates the flowrate of the fuel supplied and the flowrates of the pyrolysis products and that of the syngas:

As a reasonable approximation [16 - 18] we assume the yield and composition of pyrolysis products depending solely on the fuel composition (Equations (1)&(2)). The products’ composition according to [19, 20] (Table 1) was used in the calculation,

\[ M_c = K_c * M_f \]  
\[ m_w = k_w * M_f + \mu_w + M_w \]  (2)

### Table 1. Yield of pyrolysis products [19, 20].

<table>
<thead>
<tr>
<th>Component</th>
<th>yield, % mass</th>
<th>gas composition, % mass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gas (C\textsubscript{<em>{x}}H\textsubscript{</em>{y}}O\textsubscript{_{z}})</td>
<td>Char</td>
</tr>
<tr>
<td>Cellulose</td>
<td>28</td>
<td>25</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>6</td>
<td>94</td>
</tr>
</tbody>
</table>

Equations (3) to (6) express the conservation of carbon, hydrogen, oxygen, and nitrogen as chemical elements.

\[ m_c = k_c * M_f + 12/28 \mu_m + 12/44 \mu_l \]  (3)

\[ m_h = k_h * M_f + \mu_h \]  (4)

\[ m_o = k_o * M_f + 16/28 \mu_m + 32/44 \mu_l \]  (5)

\[ m_n = \mu_n \]  (6)

The energy balance of this zone assumes the form of the sum for enthalpies of the species entering it to the sum of enthalpies of those leaving:

\[ M_f * H_f(T_0) + M_w * H_w(T_0) + M_a * H_a(T_0) + M_i * H_i(T_0) + \mu_w * H_w(T_c) + \mu_m * H_m(T_c) + \mu_h * H_h(T_c) + \mu_d * H_d(T_c) = \mu_w * H_w(T_g) + \mu_m * H_m(T_g) + \mu_h * H_h(T_g) + \mu_d * H_d(T_g) + M_p * H_p(T_g) + M_a * H_a(T_g) + M_i * H_i(T_g) + M_c * H_c(T_c) \]  (7)

Equation (7) can be rewritten as:

\[ (\mu_w * c_w + \mu_m * c_m + \mu_h * c_h + \mu_d * c_d) * (T_c - T_0) - (M_c * c_c + M_a * c_a + M_i * c_i) * (T_c - T_0) = M_f * Q_f + M_w * Q_w + (M_w * c_w + M_p * c_p) * (T_g - T_0) \]  (8)

### 3.2.2. Combustion zone (CZ).

The char and the solid incombustibles enter the CZ already heated in the D&P zone to the combustion temperature. The part of the gas recycled to the CZ has the temperature at which the generator gas leaves the drying zone (heat loss neglected). The air, preheated due to the
heat exchange with the solids the cooling zone enters the CZ at the combustion temperature. The synthesis gas formed in the CZ flows from this zone at a high (combustion) temperature and the solids also having the combustion temperature descend from the combustion zone down to the cooling zone.

We assume that the char is completely consumed in the CZ. Also, we assume that, as the combustion temperature controlled at 900°C is sufficiently high, the conversion of the recycled generator gas is complete and the synthesis gas contains no tractable species except nitrogen, carbon mono- and dioxide, hydrogen, and water vapor [21].

The material and energy balance for the CZ relates the flowrates of the syngas components to those of MW char and incombustibles, air, and recycled gas.

All the nitrogen supplied with the air flow enters the syngas and further generator gas, the fraction of the generator gas, which is withdrawn from the reactor, contains all the nitrogen supplied with air. As this is \((1-\alpha)\mu_n\),

\[
\mu_n = M_n/(1-\alpha) \quad (9)
\]

\[
M_n = N*M_o \quad (10)
\]

where the mass ratio of nitrogen and argon sum to oxygen in air; \(N = 3.301\).

The carbon enters CZ as the char and carbon contained in the recycled generator gas, leaving are monoxide and dioxide in the syngas.

\[
12/28\mu_m + 12/44\mu_d = M_c + \alpha m_c \quad (11)
\]

The balance of hydrogen in CZ includes water vapor and hydrogen-containing components of the generator gas.

\[
2/18\mu_h + \mu_m = \alpha m_h + 2/18\alpha m_w + 2/18\alpha M_w \quad (12)
\]

And the oxygen balance includes that supplied with air, water vapor, and oxygen-containing components of the generator gas.

\[
16/18\mu_o + 16/28\mu_m + 32/44\mu_d = M_o + 16/18\alpha M_w + \alpha m_o \quad (13)
\]

The energy balance in the CZ takes the form of the equality of the sum of the enthalpies of air, char, solid incombustibles, and generator gas entering the combustion zone each with its own temperature \((T_c, T_v, T_c, \text{and } T_g)\), to the sum of the enthalpies of syngas and incombustibles, which leave the CZ having the combustion temperature \((T_c)\).

\[
M_n*H_n(T_c) + M_o*H_o(T_c) + M_i*H_i(T_c) + M_v*H_v(T_c) + M_r*H_r(T_c) + \alpha m_n*H_n(T_g) + \alpha m_o*H_o(T_g) + \alpha m_i*H_i(T_g) + \alpha m_v*H_v(T_g) = \mu_o*H_o(T_c) + \mu_m*H_m(T_c) + \mu_i*H_i(T_c) + \mu_v*H_v(T_c) + \mu_n*H_n(T_c) + \mu_r*H_r(T_c) + \mu_v*H_v(T_c) + \mu_i*H_i(T_c) + \alpha m_o*H_o(T_g) \quad (14)
\]

The enthalpy of the ceramic balls and ash, which enter the CZ at the combustion temperature and leave it at the same temperature, cancels.

### 3.2.3. Cooling zone.

The ceramic balls and the ash descend from CZ at the combustion temperature. The solids lend the sensible heat to the ascending air flow. The flow of the ceramic balls is controlled to secure equal heat capacity of the solids’ flow and that of the countercurrent air flow.

\[
M_n*c_n + M_o*c_o = M_i*c_i + M_v*c_v \quad (15)
\]
This condition secures \[15\] the highest energy efficiency of the conversion reaction as it provides preheating of the air flow, while negligible heat loss with the solids discharged from the reactor. We have already used this condition setting in Eq. (14) the temperature of the air inflowing the combustion zone to \(T_c\).

### 3.3. Calculations

For a given flowrate and composition of MW \((M_f, M_w, M_o)\), the 14 equations set (1) – (6), (8) – (15) relates 17 variables \(M_c, m_w, m_c, m_b, m_o, m_n, M_o, M_n, \mu_n, \mu_o, \mu_w, \mu_m, \mu_d, T_g, T_c, \alpha\). To resolve it to determine \(T_c\) and \(T_g\), for fixed \(M_o\) and \(\alpha\) (or alternatively, to determine \(\alpha\) necessary to maintain a prescribed \(T_c\) for a fixed \(M_o\)) we need one additional equation to close the set.

Under the conditions described afore, an extended high-temperature \((T_c)\) zone from the combustion zone up to the pyrolysis zone – one can expect in this zone the establishment of chemical equilibrium by the reaction

\[
CO_2 + H_2 \leftrightarrow CO + H_2O
\]

Since the partial pressure of the gases involved in reaction (16) is proportional to their mass flowrates, the chemical equilibrium condition becomes

\[
\mu_d^{*} \mu_b = K^{*} \mu_m^{*} \mu_w
\]

where \(K = (44*2)/(28*18)*\(\kappa(T_c)\)); is the equilibrium constant \(\kappa\) is a known temperature function. Equation (17) closes the equations set.

As the generator gas is burnt in an aftercombustor, the control for the process should provide a maximum heating value of the generator gas, while meeting the restrictions on the combustion temperature and generator gas temperature. The dependences of these temperatures on the control parameters \(M_o\) and \(\alpha\) are monotonic. The higher is the oxygen flowrate, the higher is net heat release in the combustion zone (Eq. (14)) and the combustion temperature. The net heat release in the combustion zone equals the sum of evaporation heat for the MW humidity, enthalpy of the pyrolysis reaction, and sensible heat of the generator gas (compare Eqs. (8) and (14)), therefore. a higher oxygen flowrate also increases the generator gas temperature. The increased recycle rate \(\alpha\), to the contrary, results in a lower combustion temperature as the recycled gas brings to the combustion zone extra endothermic oxidants (steam and carbon dioxide) and pyrolysis tar to be converted to syngas.

The calculations were performed according to the following iterative procedure. The desirable combustion temperature preset: \(T_c = 900^\circ\text{C}\).

The known MW composition promptly yields the flowrates of the pyrolysis products, the zero approximation for the oxygen flowrate was set at the oxygen to carbon (char) molar ratio of 1/2 (complete char oxidation to carbon monoxide). Further, the recycle rate was calculated to adjust \(\alpha\) to the preset \(T_c\) and the generator gas temperature was calculated. Once the calculated generator gas temperature was below 100\(^\circ\text{C}\), the oxygen flowrate was increased and the procedure repeated to the convergence.

The values according to NIST Chemistry WebBook [22] (Table 2) were used for the species’ formation enthalpies and heat capacities. The heat capacities were assumed constant and equal to those average within 300…1200 K range.
Table 2. Thermochemical data used in the calculations.

<table>
<thead>
<tr>
<th>Species</th>
<th>H₂</th>
<th>CH₄</th>
<th>H₂O</th>
<th>CO</th>
<th>N₂</th>
<th>O₂</th>
<th>CO₂</th>
<th>C_nH_m</th>
<th>C</th>
<th>Tar*</th>
<th>Ash*</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₀, MJ/kg</td>
<td>0</td>
<td>-4.68</td>
<td>-14.24</td>
<td>-3.95</td>
<td>0</td>
<td>0</td>
<td>-8.94</td>
<td>-2.36</td>
<td>0</td>
<td>-1.94</td>
<td>0</td>
</tr>
<tr>
<td>cₜ, kJ/kg/K</td>
<td>15.00</td>
<td>2.50</td>
<td>2.20</td>
<td>1.14</td>
<td>1.13</td>
<td>1.04</td>
<td>1.12</td>
<td>2.60</td>
<td>1.30</td>
<td>2.20</td>
<td>1.00</td>
</tr>
</tbody>
</table>

*Calculated for the gross formula of tar C₁₈H₁₀O.
*Heat capacity of alumina was assigned for ash and ceramic balls.

4 Calculation results and discussion

The calculations were performed for the MW dry mass composition of PP/cellulose/ash at mass ratio of 20/63/17 and humidity varied from 0 to 40%.

Figs. 2 - 3 present the dependences of the generator gas temperature, recycle rate, and air flowrate on the MW humidity.

![Fig. 2. The dependences of the generator gas temperature (1) and recycle rate (2) on MW humidity.](image-url)
Fig. 3. The dependence of air flowrate on MW humidity. Relative to: 1 - combustible mass; 2 - total mass.

For the humidity below 15%, the generator gas temperature proves higher than 100°C. Within this humidity range, the oxygen flowrate relative to the combustible mass remains constant, that necessary for complete oxidation of char. The recycle ratio in this low-humidity range decreases with humidity, as the generator gas grows cooler and contains more steam, less generator gas is sufficient to control the combustion temperature. The generator gas temperature for MW humidity higher than 15 % remains constant, 100°C, that minimum necessary to provide evaporation of the fuel humidity. The air flowrate must be increased with humidity to provide the heat sufficient for evaporation. The higher recycle ratio reflects the necessity to provide more generator gas to control the combustion temperature with the increasing net heat release in the combustion zone.
The syngas produced in the combustion zone is low-caloric. Its quality expectedly decreases with MW humidity due to higher content of steam and carbon dioxide (Fig. 4). Still it remains combustible and with a part of pyrolysis gas can be efficiently afterburnt in a gas burner to secure ultimate neutralization and generation of heat. The calculated adiabatic temperature for stoichiometric combustion of the generator gas ($T_{ad}$) decreases practically linear in MW humidity from 1620°C for zero humidity to 1000°C for 40%. For the humidity up to 40%, the combustion temperature remains sufficiently high to secure efficient afterburning of the generator gas without any additional fuel.

5 Conclusion

The afore presented calculations show that a typical MW can be efficiently gasified using the process of [11]. The control of the process is straightforward: the higher air flowrate increases both the combustion temperature and the temperature of the generator gas, while higher generator gas recycle rate reduces the combustion temperature. Similar to the updraft process with a solid granular heat carrier [10], this process promises a high stability to inevitable variations in the fuel composition, as a massive high-temperature zone provides a thermal inertia and conditions for averaging the fuel composition. Within a wide variation of the MW humidity, the process remains sustainable in energy without any additional fuel to support a controllably high combustion temperature. The generator gas is combustible and can be efficiently used for heat generation.

MW often contains a substantial fraction of chlorinated plastics (syringes, transfusion bags, etc.). This process shares with [10] the feature of an extended drying and pyrolysis zone in the upper part of the reactor. In this zone, the hydrogen chloride (the major pyrolysis product for chlororganics) can be neutralized with the mineral components of the fuel charge. Thus, the chlorine leaves the reactor as innocuous calcium chloride in the ash. In the case of...
anticipated high chlorine content in MW, calcium carbonate or lime can be added to MW to guarantee the chlorine removal from the gas flow [23, 24].

Another feature of the process particularly suitable for processing MW with energy generation, is the stabilization of the combustion zone at the tuyers for recycled generator gas. This provides an option for charging the MW to be incinerated in disposable plastic or cardboard containers and bags, which should be destroyed in the pyrolysis zone; preferably, the same containers used for MW collection. This reduces to minimum the risks for MW spread during transportation and charging.

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References

22. NIST Standard Reference Database Number 69 (2022)