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Research Article

Valorization of Hazardous Waste in Desalination of Water and Drying of Agricultural Products

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ABSTRACT

The recovery of waste is an extremely important operation. Indeed, environmental protection and economic growth are at least the two benefits of waste recovery. In this work, we present the pyrolysis of hazardous waste as a potential source of water desalination and drying of African products. This waste makes it possible to produce more than 100,000 m3/day and to dry more than 3,000 kg of solid per day. Natural resources such as oil and gas are being replaced by hazardous waste in these operations, which favors sustainable development.

Keywords: Hazardous waste; Pyrolysis; Water desalination; Drying; Sustainable development

INTRODUCTION

World population growth, industrialization and urbanization in our modern societies have been accompanied by a sharp increase in demand for primary energy. According to the International Energy Agency (IEA), global primary energy production1 was estimated at 13,371 GTep in 2012. Energy production should continue to increase, reaching around 18.5 Gtoe in 2035. Hence the need to recover waste to cover part of the energy needs. It is in this context that the development of so-called bio-sourced energies is of great interest. Pyrolysis is one of the processes used to recover waste. In this article, we seek to discover the potential for recycling hazardous waste produced by an industrial company that recycles organic waste solvents. We have chosen to recover this waste by pyrolysis followed by combustion. The calorific power produced is used to produce distilled water and the drying of an agri food product [1].

MATERIALS AND METHODS

Research significance

The design and testing of waste recovery systems are the subject of work by several research laboratories around the world. Whatever the size and type of waste to be recovered, the performance of these systems depends not only on design and technology, but also on operating conditions. Therefore, this study focuses on the evaluation of waste recovery process to produce distilled water and dry an agricultural product. The results obtained can provide indications of the opportunities offered by the conversion of hazardous waste into a source of profit [2].

Experimental setup

The experimental set up is illustrated in Figure 1. It consists of a pyrolysis enclosure, a burner, heat exchangers E1, E2 and E3, a dryer and an air humidification-dehumidification system. The fuel gas, obtained by pyrolysis of the waste, is directed to the burner where it undergoes combustion with excess air.

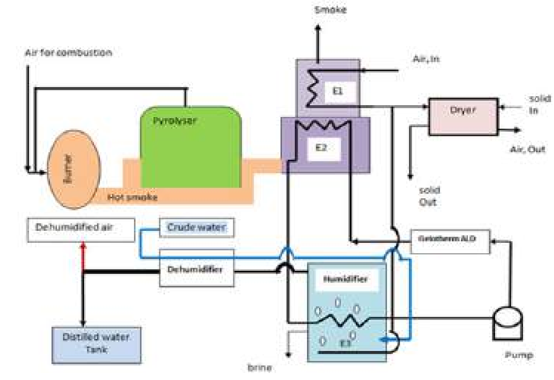

Figure 1: Experimental set up.

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The heat of combustion will be used for pyrolysis of waste, drying of agricultural products and for the production of pure water by the Humidification-Dehumidification (HDH) technique [3].

Le pyrolyzer

Pyrolyzer is an enclosure, made of stainless steel with a thickness of 5 mm and a volume of 800 liters, in which 1 kg of hazardous waste undergoes pyrolysis at 550°C. It is built according to the rules adopted by the authors. A fuel oil obtained will be directed to the burner for combustion. The lower calorific value (PCI) of the pyrolysis gas is measured using a calorimeter. Its value is 35,000 kJ. The waste used consists of solid plastic and polluting organic solvents [4].

The burner

It is of the MTCB type. It ensures the combustion of the pyrolysis gas with an excess of air and a yield, ɳ. The heat of combustion (Qcomb), will be used to carry out the pyrolysis (Qpyr) and heat the air, part of which will be used to dry an agricultural product (Qair, dry) and the other part (Qair, hum) will be used as moisture carrier in the humidification-dehumidification system [5].

Hence a thermal balance on the system can be described by the following equation:

$$\mathbf{PCI} * \eta = \mathbf{Qcomb} = \mathbf{Q_{Pyr}} + \mathbf{Q_{air,dry}} + \mathbf{Q_{air,hum}} \quad (1)$$

The heat losses are neglected here because the system is perfectly insulated.

Heat exchanger E1

Is a gas-gas heat exchanger, of the tube-shell type whose exchange area is 1 m^2. An air flow rate m_{Air} enter at temperature $T_{A,I}$ and comes out at temperature $T_{A,O}$. This air flow will be divided into two flows: A flow, $m_{Air,Dry}$, is used to dry one agricultural product and the other, $m_{Air,Hum}$, will be used as a vapor carrier in the humidifier. A mass balance on the air heated in E1 is described by the following equation:

$$m_{Air} = m_{Air,Dry} + m_{Air,Hum} \quad (2)$$

Heat exchanger E2

Is a tube/shell type liquid/gas exchanger fitted with baffles. A flow of thermo fluid (gilotherm_ALD), m_{ALD}, coming from a tank with heat capacity, CP_{ALD}, enters the exchanger at a temperature $T_{ALD,I}$ and leaves at the temperature $T_{ALD,O}$. Note that this thermo fluid can reach relatively high temperatures (more than 350°C) but its heat capacity varies depending on the temperature [6]. The amount of heat gained by the thermo fluid without change of physical state is:

$$Q_{ALD} = m_{ALD} * CP_{ALD} * (T_{ALD,O} - T_{ALD,I}) \quad (3)$$

Heat exchanger E3

Is a plate type liquid/liquid exchanger. Its role is to heat the raw water to be desalted by heat transfer from the oil to the liquid water. The heat balance on the E3 exchanger is given by the following equation:

$$m_w * Cp_w * (T_O^w - T_I^w) = m_{ALD} * CP_{ALD} * (T_{ALD,I}^{hum} - T_{ALD,O}^{hum}) \quad (4)$$

m_W: mass flow rate of raw water to be treated,

Cp_w: Heat capacity of raw water,

$T^w{}_0$: Water temperature at the outlet of HDH,

$T^w{}_1$: Water temperature at the inlet of HDH.

m_{ALD}, CP_{ALD} are respectively the mass flow, the heat capacity, the temperature at the inlet and that at the outlet of the humidifier, thermo fluid.

Dryer

It is a heat-insulated rotary cylinder of 2 m length, where hot air circulates against the current with the solid to be dried. It is built according to the rules adopted by Kechaou N. A mass balance of water is given by the following equation [7].

$$m_{ss} * (X_I - X_O) = m_{As} * (Y_O - Y_I) \quad (5)$$

Where:

m_{ss}: Dry solid flow

X_I, X_O: are respectively the water vapor masses per kg of dry solid (kg/kg) at the inlet and at the outlet of the dryer,

m_{As}: dry air mass flow,

Y_O,Y_I: are respectively the water vapor masses per kg of dry air (kg/kg) at the outlet and at the inlet of the dryer

Humidification-Dehumidification System (HDH)

It is a system used to produce distilled water from raw salt water. In fact, the raw water enters a vertical column where it will be heated by a hot oil through the exchanger E3. An air flow, $m_{Air,Hum}$ is humidified by contact with hot raw water. A mass humidification balance is given by the following equation:

$$m_{Air,Hum} * (Y_O^{Hum} - Y_I^{Hum}) = m_w^{Evap} \quad (6)$$

Where:

$m_{Air,Hum}$= mass flow of hot air from the heat exchanger E1.

Y_0^{Hum}, Y_1^{Hum}=are respectively specific humidities of the air at the outlet and the inlet in the humidifier.

m_w^{Evap}=mass flow of water evaporated by humidification. note that is negligible compared to the mass flow of raw water to be treated, m_W.

Dehumidification is carried out in two successive condensers with vertical tubes. The mass flow rate of distilled water obtained by condensation of the water vapor contained in the air is given by the following equation:

$$m_{Air,DeHum} * (Y_I^{deHum} - Y_0^{deHum}) = m_w^{Dist} \qquad (7)$$

Where:

$m_{(Air,DeHum)}$: Dry air mass flow in the dehumidifier,

Y_I^{deHUm}, Y_0^{deHUm} are respectively the water vapor masses per kg of dry air at the inlet and at the outlet of the dehumidifier.

m_w^{Dist}: Distilled water flow produced by HDH.

The crude water's chemical composition at 20°C is indicated in Table 1.

Table 1: Crude water's chemical composition at 20°C.

Composition	mg/l
Ca^{2+}	152
Mg^{2+}	192
Na^{+}	231
K^{+}	98
HCO_3^-	484
SO_4^{2-}	365
Cl^-	335
Salinity	1857

For the measurement of the Relative Humidity (RH), an thermo-hygrometer S.P.S.I. (B) type, which gives the measured values of temperature in the range of (-40°C; 140°C) and RH in the range of (0; 100%) with accuracy of 2% [8].

RESULTS AND DISCUSSION

Vapor content difference

Figure 2 shows vapor content difference ΔX versus liquid water temperature. When the temperature increased, the vapor content increased also. For instance, if water temperature is 60° C, then vapor is, almost 150 g vapor/kg dry air. However, if the water temperature is 80°C, the vapor content, ΔX, is more than 500 g v/kg a. So the temperature has a direct effect on the vapor content. These results are confirmed by some authors [9].

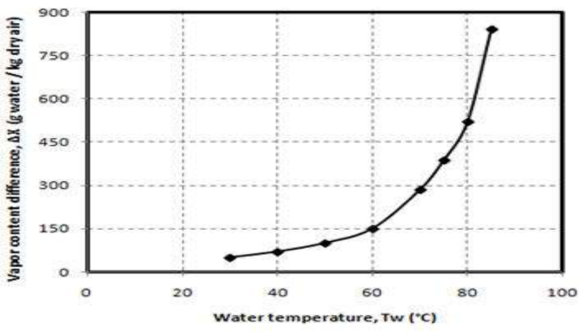

Figure 2: Vapor content difference versus water temperature.

Distilled water flowrate

Figure 3 illustrates the distilled water flow rate change with water temperature. For all air flow rates values, the maximum value of distilled water flow rate is obtained when liquid temperature is 85°C. Above 85°C, the humidifier is no longer operational since the air rich in vapor becomes very fast and it causes jets of the liquid [10].

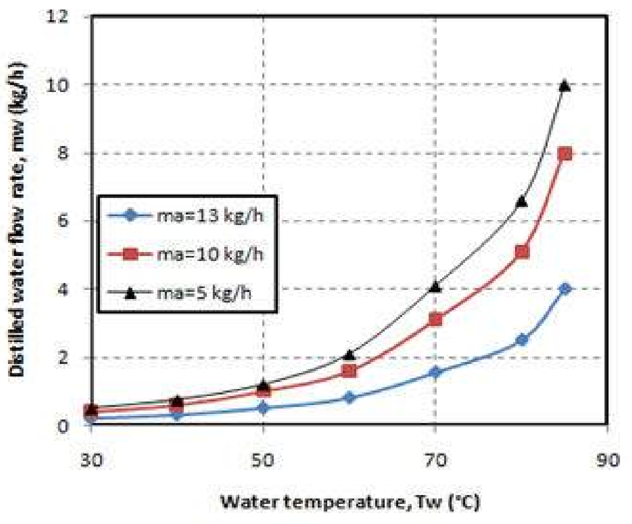

Figure 3: Distilled water flow rate versus water temperature.

Dry product flow rate

The performance of the dryer is measured by the dry product flow rate. Figure 4 illustrates the variation of the dry product flow rate with air temperature and air flow rate. The maximum value of dry product flow rate is obtained when air temperature is 85°C and air flow rate is 3 kg/h [11].

Beyond 85°C, the risk of oxidation and characteristics changes of the solid product are very high.

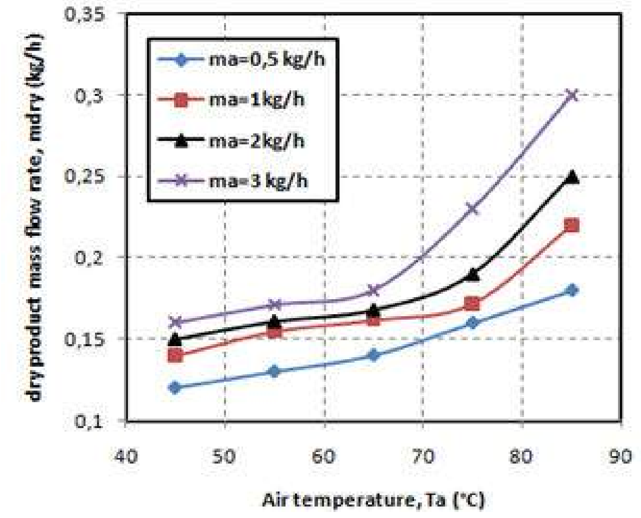

Figure 4: Dry product mass flow rate versus air temperature.

Determination of operational thermal fluid flowrate

The thermal fluid known as gelotherm-ALD is used to transport heat from the exchanger E2 to the exchanger E3 where it will heat the raw water up to a temperature of 85°C. This themo fluid has the advantage of being heated to a temperature above 300°C without change of physical state and without risk of oxidation, but these characteristics such as the viscosity and the density change with the variation of the temperature [12].

Figure 5 illustrates the variation of outlet temperature of the gelotherm-ALD with its mass flow rate for constant heat source. This variation is explained by the variation in its heat capacity.

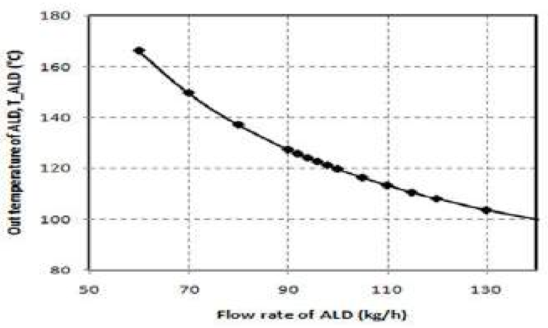

Figure 5: Out temperature of thermal fluid versus flow rate of ALD.

Figure 6 illustrates the variation of the specific heat of the gelotherm-ALD as a function of the temperature. Its value is between 1.93 kj/kg K and 2.9 kj/kg K.

Experiments have shown that the thermo-fluid must exit from the exchanger E2 at a temperature of 125°C. Therefore, the operating mass flow rate of the gelotherm is 92 kg/h. This flow rate heats 100 kg/h of raw water to a temperature of 85°C in the exchanger E3. Daily production is around 100 liters of distilled water and 3 kg of dry agricultural product.

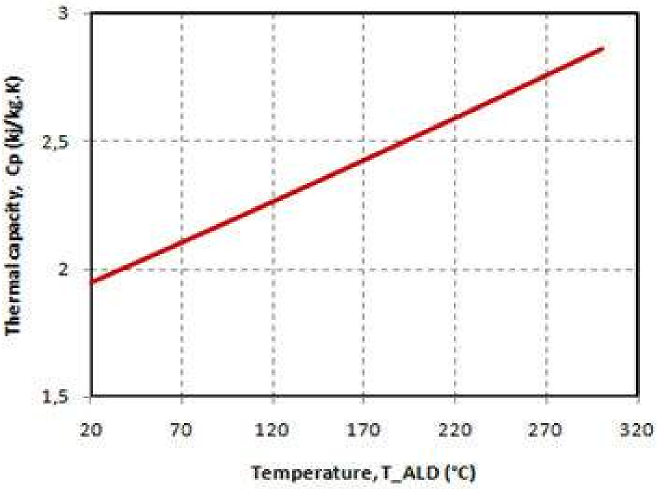

Figure 6: Thermal capacity of thermal fluid versus temperature.

Thermal power needed

The experimental setup makes it possible to heat the air, to dry an agricultural product and the thermo fluid for the desalination of water. The experimental study reveals that 10 kg/h of distilled water and 0.3 kg/h of dry agricultural product can be produced by consuming 0.5 kg/h of hazardous waste.

The figure illustrates the heat output budget for each operation. Indeed the pyrolysis heat of 0.5 kg of hazardous waste will be used, mainly, for the production of distilled water and pyrolysis. The air heating to a part equal to 3.73% of the heat offered by the waste. This is explained by the low heat capacity of the air and the low need for hot air (Figure 7).

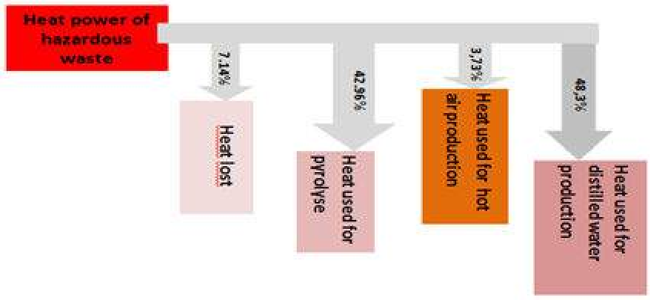

Figure 7: Energy fraction used by each operation.

The calorific power lost is 7.14% which is higher than that used to heat the air despite the almost perfect thermal insulation. This could be explained by an exergetic analysis of the processes.

Sustainable development

This assembly allows the desalination of water and the drying of food products using hazardous waste as an energy source. This design makes it possible to reduce the consumption of raw materials such as wood, natural gas, petroleum and its derivatives, etc. Therefore, the contribution in protecting the environment is unequivocally ensured since the release of polluting gases such as CO_2, SO_2, NO_x as well as heavy metals is completely absent. In addition, the consumption of natural resources is nonexistent with this experimental setup.

CONCLUSION

The performances of hazardous waste pyrolysis and combustion have been investigated. The following conclusions can be drawn based on the experimental results.

- Increasing the water temperature improved the vapor content difference in air, the desalination productivity and dry solid product productivity.
- The thermal powers consumed by pyrolyse operation and water desalination is greatest fraction of energy offered by hazrdous waste.
- Energy losses due to destruction of exergy are relatively high. Hence an exergetic analysis is essential.
- Waste production is 50 tonnes/day, which makes it possible to produce 100,000 m/day of distilled water and 3,000 kg/day of dry agricultural product.
- This experimental setup is in accordance with the rules of environmental protection and sustainable development.

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