# Corso di Dottorato di Ricerca in Scienze della Vita e dell'Ambiente - Ciclo XXXV

# *Energy recovery from industrial processes using chemical substances*

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## ABSTRACT

The research aims to reduce the environmental impact and recover energy in industrial processes that use chemicals. A company, which turns virgin wood into end products, is taken as a case study. The purpose is to recover useful energy by optimizing the abatement of VOC pollutants and reusing the raw material waste. A mass balance of the entire abatement system was carried out by characterization of the inlet-outlet flow and samples are analyzed in lab. Also, various CFD simulations are in progress to evaluate the actual abatement system and study a new innovative one.

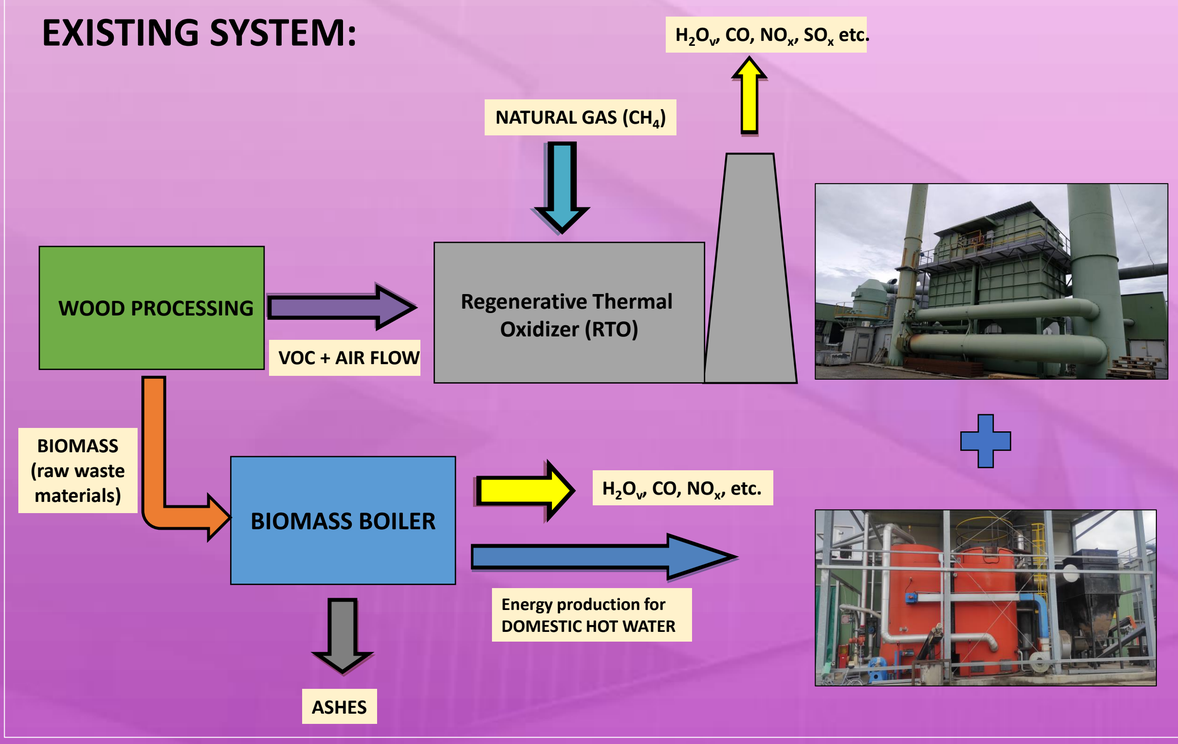

## INTRODUCTION

Environmental impact and energy recovery from VOC abatement processes are evaluated firstly with a bibliographic research. Technologies and plants active in the surrounding area of Ancona are analyzed. The doctorate co-financing company has a proven experience in environmental and energy sector. By this know-how it was possible to select an industry in the woodworking sector. This company turns virgin wood into end products such as doors and furnishing. For the regulatory framework, there are strict limits on atmospheric emissions by industrial processes and several monitoring operational procedures. The study of innovative solutions to reduce the pollutant emissions and recover energy is essential.

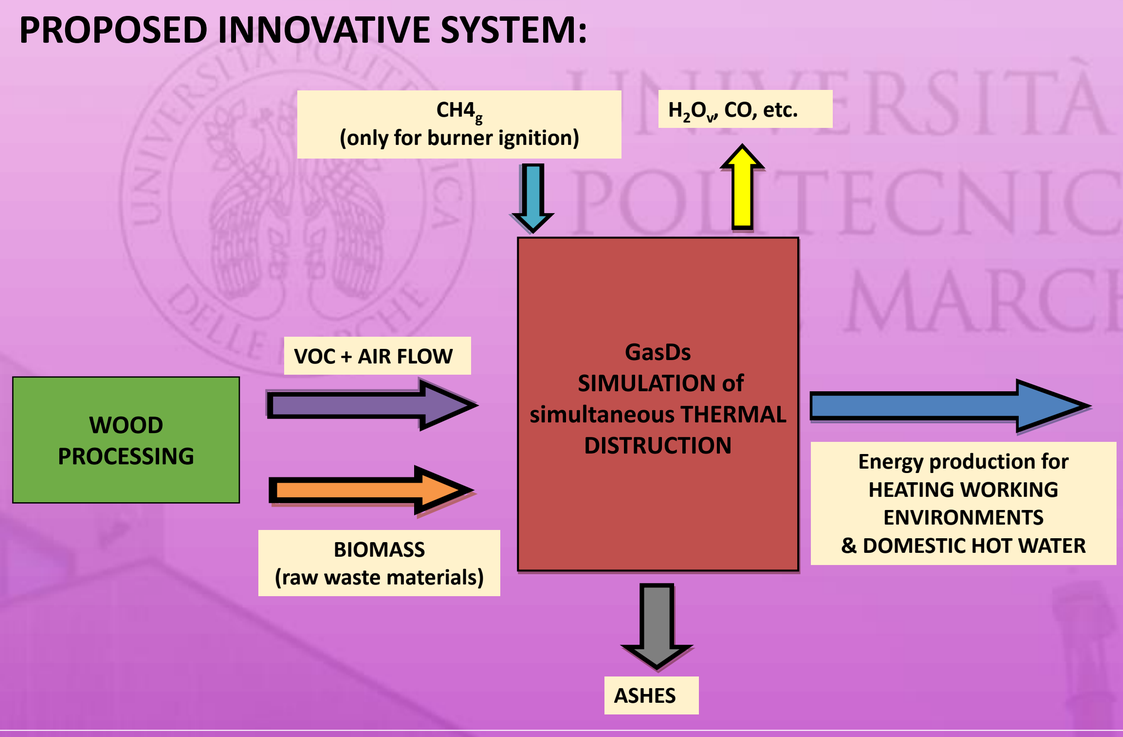
## MATERIALS & METHODS

The measurements and sampling carried out shown the trend of VOC flows produced in relation with raw materials waste production. These are based on annual production and types of painting processing used. The existing abatement system has a high yield (95-98%) but a very high consumption of methane fuel.
Therefore, an alternative and innovative scenarios of the abatement system are hypothesized. Thus, are studied through Computational Fluid Dynamics (CFD) simulation in collaboration with the Polytechnic of Milano. **GasDs software** is being used to evaluate the existing system and study the scenarios. In them is hypothesized to recreate a simultaneously thermal destruction of the biomass (raw material waste) and the air flow with VOCs that comes from the wood processing.

### EXISTING SYSTEM:



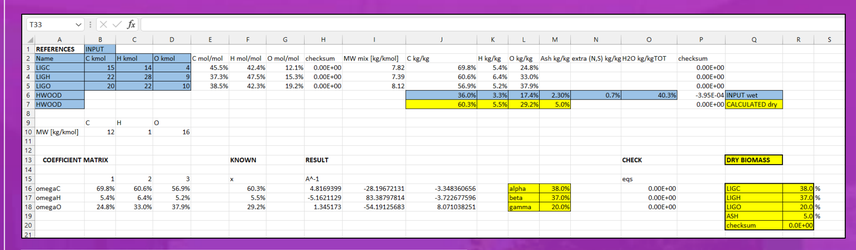

### PROPOSED INNOVATIVE SYSTEM:




## PRELIMINARY RESULTS – GasDs CFD SIMULATION

### 1. PRELIMINARY OPERATIONS

- Feedstock composition;
- CHNSO Analysis;
- Umidity content.



| REFERENCES | INPUT | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | C kmol | H kmol | O kmol | C mol/mol | H mol/mol | O mol/mol | checksum | MW mix [kg/kmol] | C kg/kg | H kg/kg | O kg/kg | Ash kg/kg | extra (N,S) kg/kg | H2O kg/kgTOT | checksum | | | | |
| LIGC | 15 | 14 | 4 | 45.5% | 42.4% | 12.1% | 0.00E+00 | 7.82 | 69.8% | 5.4% | 24.8% | | | | 0.00E+00 | | | | |
| LIGH | 22 | 28 | 9 | 37.3% | 47.5% | 15.3% | 0.00E+00 | 7.39 | 60.6% | 6.4% | 33.0% | | | | 0.00E+00 | | | | |
| LIGO | 20 | 22 | 10 | 38.5% | 42.3% | 19.2% | 0.00E+00 | 8.12 | 56.9% | 5.2% | 37.9% | | | | 0.00E+00 | | | | |
| HWOOD | | | | | | | | | 36.0% | 3.3% | 17.4% | 2.30% | 0.7% | 40.3% | -3.95E-04 | INPUT wet | | | |
| HWOOD | | | | | | | | | 60.3% | 5.5% | 29.2% | 5.0% | | | 0.00E+00 | CALCULATED dry | | | |
| | C | H | O | | | | | | | | | | | | | | | | |
| MW [kg/kmol] | 12 | 1 | 16 | | | | | | | | | | | | | | | | |
| COEFFICIENT MATRIX | | | | KNOWN | | RESULT | | | | | | | CHECK | | | DRY BIOMASS | | | |
| | 1 | 2 | 3 | x | | A^-1 | | | | | | | eqs | | | | | | |
| omegaC | 69.8% | 60.6% | 56.9% | 60.3% | | 4.8169399 | -28.19672131 | -3.348360656 | | alpha | 38.0% | | 0.00E+00 | | | LIGC | 38.0% | | |
| omegaH | 5.4% | 6.4% | 5.2% | 5.5% | | -5.1621129 | 83.38797814 | -3.722677596 | | beta | 37.0% | | 0.00E+00 | | | LIGH | 37.0% | | |
| omegaO | 24.8% | 33.0% | 37.9% | 29.2% | | 1.345173 | -54.19125683 | 8.071038251 | | gamma | 20.0% | | 0.00E+00 | | | LIGO | 20.0% | | |
| | | | | | | | | | | | | | | | | ASH | 5.0% | | |
| | | | | | | | | | | | | | | | | checksum | 0.0E+00 | | |

Representative preliminary file

| Component | wt. % (wet basis) |
|---|---|
| Carbon (C) | 36.0 |
| Hydrogen (H) | 3.27 |
| Nitrogen (N) | 0.6 |
| Sulfur (S) | 0.07 |
| Oxygen (O) | 17.4 |
| Ash | 2.30 |

### 2. SIMULATION

Imput parameters:

- Number of components;
- Number of reactions;
- Reactor geometry;
- Flowrate;
- Start-up T;
- %V/v of the gaseous agent.

```
!Number of components =! 50
!Componenets names     ! O2,N2,CO,CO2,H2,H2O,CH4,C2H6,C2H4,C3H6,C3H8,C2H2,LVG,XYLAN,ALD3,
!                      ! CH3OH,HCOOH,HMFU,COUMARYL,FENOL,HAA,GLYOX,MECHO,CH2O,ETOH,BENZ,
!                      ! TOLUO,FE2MACR,H2OL,ASH,CHAR,CELL,CELLA,HECELL,HCE1,HCE2,LIGC,
!                      ! LIGCC,LIGOH,LIG,LIGH,LIGO,COH2S,CO2S,COS,CH4S,C2H4S,CH3OHS,ACQUA,
!                      ! CH2S
!Number of reactions =    ! 30
!Reactions ID number      ! 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,
!                         ! 25,26,27,28,29,33
!Number of Particles      (max=10)  ! 1
!Number of Particle sectors (max 30) ! 1
!Uniform Particles initial Temperature (K)! 300
!Uniform initial Pressure (Ata)          ! 1.0

!---------------------------PROCESS -------------------
! Equipment surface (m^2)                          =! 0.785
! Equipment Height  (m  )                          =! 5
! Void fraction (Void volume/equipment Volume) *100 =! 55
! Number of Volume Elements (max=20)               =! 2
! Feed Flow (Nm^3/s)    -------------------------   =! 1
! Feed Temperature (K)  -------------------------   =! 1200
! Bulk Initial Temperature (K)-------------------   =! 300
! Top Radiant Temperature (K) (0. = non active)     =! 0.0
! Top Transfer_Line Height (m) (0.= non active)     =! 0
! Components feed volume fractions %  :!
!       - Not reported values are set=0.0
!       (values are normalised by the program)
! Total data =!  3
N2    75.24
O2    20.00
CH3OH    4.762
```

Input file

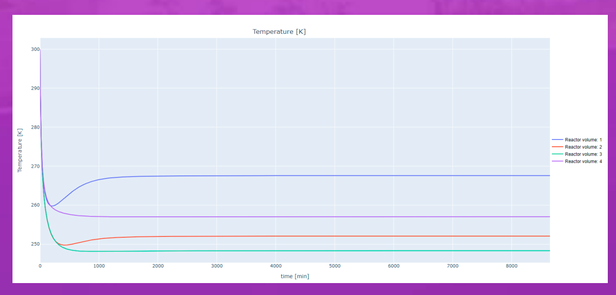
### 3. EXPECTED RESULTS

| SOLID# 1 | FEED (kg/h) | wt% | EXIT (kg/h) | wt%% |
|---|---|---|---|---|
| ASH | 2.9823 | 2.9823 | 2.9823 | 99.912 |
| CHAR | 0.0000 | 0.0000 | 0.32752E-07 | 0.10972E-05 |
| CELL | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| CELLA | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| HECELL | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| HCE1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| HCE2 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| LIGC | 22.666 | 22.666 | 0.21045E-21 | 0.70505E-20 |
| LIGCC | 0.0000 | 0.0000 | 0.14976E-09 | 0.50173E-08 |
| LIGOH | 0.0000 | 0.0000 | 0.52549E-13 | 0.17605E-11 |
| LIGH | 22.069 | 22.069 | 0.22497E-20 | 0.75370E-19 |
| LIGO | 11.929 | 11.929 | 0.66360E-16 | 0.22232E-14 |
| LIG | 0.0000 | 0.0000 | 0.88418E-14 | 0.29622E-12 |
| COH2S | 0.0000 | 0.0000 | 0.68645E-08 | 0.22997E-06 |
| COS | 0.0000 | 0.0000 | 0.32216E-14 | 0.10793E-12 |
| CH4S | 0.0000 | 0.0000 | 0.52574E-10 | 0.17613E-08 |
| C2H4S | 0.0000 | 0.0000 | 0.69278E-10 | 0.23209E-08 |
| CH3OHS | 0.0000 | 0.0000 | 0.28503E-15 | 0.95490E-14 |
| CO2S | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| ACQUA | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| CH2S | 0.0000 | 0.0000 | 0.57512E-09 | 0.19267E-07 |
| H2OL | 40.264 | 40.264 | 0.71712E-13 | 0.24025E-11 |
| TOTAL | 99.910 | | 2.9823 | |

Mass balance of SOLID compounds

| GAS PHASE | FEED (kg/h) | wt% | EXIT (kg/h) | wt% | mol% |
|---|---|---|---|---|---|
| N2 | 3385.3 | 72.674 | 3385.4 | 71.193 | 71.919 |
| O2 | 1027.8 | 22.065 | 559.88 | 11.774 | 10.413 |
| H2 | 0.0000 | 0.0000 | 0.28701E-03 | 0.60356E-05 | 0.84725E-04 |
| H2O | 0.0000 | 0.0000 | 344.48 | 7.2442 | 11.380 |
| CO | 0.0000 | 0.0000 | 0.14389 | 0.30258E-02 | 0.30571E-02 |
| CO2 | 0.0000 | 0.0000 | 463.99 | 9.7574 | 6.2744 |
| CH4 | 0.0000 | 0.0000 | 0.42012E-03 | 0.88349E-05 | 0.15585E-04 |
| C3H6 | 0.0000 | 0.0000 | 0.19137E-06 | 0.40245E-08 | 0.27065E-08 |
| C3H8 | 0.0000 | 0.0000 | 0.59022E-13 | 0.12412E-14 | 0.79655E-15 |
| C2H2 | 0.0000 | 0.0000 | 0.12257E-03 | 0.25776E-05 | 0.28015E-05 |
| C2H4 | 0.0000 | 0.0000 | 0.68510E-03 | 0.14407E-04 | 0.14533E-04 |
| C2H6 | 0.0000 | 0.0000 | 0.88281E-08 | 0.18565E-09 | 0.17472E-09 |
| CH2O | 0.0000 | 0.0000 | 0.52763E-03 | 0.11096E-04 | 0.10458E-04 |
| CH3OH | 245.07 | 5.2609 | 0.24375E-03 | 0.51259E-05 | 0.45272E-05 |
| HCOOH | 0.0000 | 0.0000 | 0.11584E-03 | 0.24359E-05 | 0.14978E-05 |
| Sub TOTAL | 4658.2 | | 4753.9 | | |
| TOTAL | | | 4755.2 | | |

Mass balance of GASEOUS compounds




Elaborated representative profiles

```
TEMPERATURE PROFILES (K)

      GAS      SOLID avg
    1426.03         300.00
   +---------+
   I         I
   +---------+
    1287.46         1419.58
   +---------+
   I         I
   +---------+
     300.00         1292.60


DETAILED COMPOSITION GAS PHASE
                wt%          mol%

H2O           7.2442       11.380
CO2           9.7574        6.2744
FUEL1      0.24245E-01  0.53531E-02
O2            11.774       10.413
N2            71.193       71.919

 Gas phase Calorific value kcal/kg :
     2.17 (wet)      2.34 (dry)
 Solid phase Calorific value kcal/kg :    3243.64
 COLD GAS EFFICIENCY (%)              :       5.34
```

Output temperature profiles