FLAME TREATMENT TECHNOLOGY AND ITS APPLICATIONS

Stefano Mancinelli
esseCI SRL Process Engineer

Via Flaminia Ternana no.386
05035 – Narni (TR) - ITALY
www.essecinet.com
SUMMARY

1. Laminar flame profile
2. Flame chemistry
3. PP surface flame oxidation mechanism
4. Flame treatment main process parameters
5. Flame treatment applications
1.1 LAMINAR FLAME PROFILE

1) Preheating zone;
2) Luminous zone;
3) Recombination zone

Temp. profile
Radicals gradient
↑
Unburned gases
convective flows
+
Radicals diffusion

AIR-GAS MIXTURE

BURNER GRID

2±3 mm

5±6 mm

AVERAGE POSITION FOR TREATMENT

• REDUCING
• NOTREATMENT
• EXCESSGAS

• OXIDIZING ZONE
• TREATMENT AREA
• EXCESSO2

3.9 October 2005

AIMCAL FALL CONFERENCE - MYRTLE BEACH - SC - USA - 19 October 2005
1.2 LAMINAR FLAME PROFILE

FLAME SPEED

*Mallard-LeChatelier Theory*

\[ S_L \sim (\beta \times RR)^{1/2} \]
\[ \beta = \text{Thermal Diffusivity} = \frac{\lambda}{\rho c_p} \]

FLAME = Dynamic balance between flame speed and mixture speed \( \Rightarrow \)
Mixt. Flow vs. Air Gap
1.3 LAMINAR FLAME PROFILE

Flame speed and mixture speed in premixed laminar flame
### 1.4 Laminar Flame Profile

<table>
<thead>
<tr>
<th></th>
<th>Gas Lean</th>
<th></th>
<th>Gas Rich</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AIR</td>
<td>O2</td>
<td>AIR</td>
<td>O2</td>
</tr>
<tr>
<td>H₂</td>
<td>4</td>
<td>4</td>
<td>75</td>
<td>94</td>
</tr>
<tr>
<td>CO</td>
<td>12</td>
<td>16</td>
<td>74</td>
<td>94</td>
</tr>
<tr>
<td>NH₃</td>
<td>15</td>
<td>15</td>
<td>28</td>
<td>79</td>
</tr>
<tr>
<td>CH₄</td>
<td>5</td>
<td>5</td>
<td>15</td>
<td>61</td>
</tr>
<tr>
<td>C₃H₈</td>
<td>2</td>
<td>2</td>
<td>10</td>
<td>55</td>
</tr>
</tbody>
</table>

**Flammability Limits (Fuel Vol. %)**
2.1 FLAME CHEMISTRY

Chain/Radical reactions:

- $M \Rightarrow R$    ; Initiating step – $k_1$
- $R+M \Rightarrow \alpha R+M'$ ; Chain Branching – $k_2$
- $R+M \Rightarrow R+P$ ; Propagating step – $k_3$
- $R+M \Rightarrow P'$ ; Terminating/Production – $k_4$
- $R \Rightarrow P''$ ; Wall destruction – $k_5$

$M = \text{reactants}; \ P,P',P'' = \text{reaction products}$

Multiplication factor $\alpha = 1 + [(k_4 + k_5) / k_2]$
2.2 $\text{H}_2 - \text{O}_2$

COMBUSTION SYSTEM

Chain Branching $\Rightarrow$ RADICAL POOL

\[
\begin{align*}
\text{H} + \text{O}_2 &\Rightarrow \text{OH} + \text{O}; \\
\text{OH} + \text{H}_2 &\Rightarrow \text{H} + \text{H}_2\text{O}; \\
\text{O} + \text{H}_2 &\Rightarrow \text{OH} + \text{H}; \\
\text{O} + \text{H}_2\text{O} &\Rightarrow 2\text{OH}.
\end{align*}
\]
2.3 METHANE OXIDATION

\[ \text{CH}_4 + \text{M} \rightarrow \text{CH}_3 + \text{H} + \text{M} \]

\[ \text{CH}_4 + \text{X} \rightarrow \text{CH}_3 + \text{XH} \]

a) methyl radicals oxidation \( \Rightarrow \text{CH}_3\text{O;CH}_2\text{O} \)

b) \( \text{C}_2\text{H}_6 \) formation and its oxidation

\( \Rightarrow \text{H}_2\text{O} \) and \( \text{CO}_2 \) production

(passing through CO).
3.1 PP surface flame oxidation mechanism

- C-H link breaking vs. C-C link breaking;
- OH > O > H >> HO₂

RH + OH → R° + H₂O;  Initiating step
RH + H → R° + H₂

R° + OH → ROH;
R° + HO₂ → ROOH;  Propagating step
R° + O₂ → ROO;
R° + H₂O₂ → ROO + OH
R° + O → RO
R° + H → RH;  Terminating step
3.2 PP surface flame oxidation mechanism

$\beta$-scission reaction:

$-\text{C––C––C--} \Rightarrow -\text{C}=\text{O} + \text{C}$

$\downarrow$

$\text{O}$

$\text{O} \Rightarrow$ alkoxy radicals $\text{RO}^\circ \Rightarrow \text{LMWOM}$. 
3.3 PP surface flame oxidation mechanism

- O/C RATIO
- IMWOM vs. LMWOM

INCREASED SURFACE ENERGY

- Chain Scission behaviour
- “Aging” behaviour
- Metallizing barrier effect & Improved surface properties
3.4 PP surface flame oxidation mechanism
3.5 PP surface flame oxidation mechanism
4.1 FLAME TREATMENT MAIN PROCESS PARAMETERS

1. Burner
2. Treater roll
3. Nip-roll

Diagram:

- Three labeled parts: Burner (1), Treater roll (2), Nip-roll (3)
- Film direction indicated by arrow

Diagram labels:
- 1: Burner
- 2: Treater roll
- 3: Nip-roll
- FILM arrow
4.2 FLAME TREATMENT MAIN PROCESS PARAMETERS

A) MIXTURE FLOW

TREATMENT (dyne/cm)

MIXTURE FLOW (m³/h)

Q1

Q2
4.3 FLAME TREATMENT MAIN PROCESS PARAMETERS

TREATMENT LEVEL vs. MIXTURE FLOW CURVES (AT DIFFERENT LINE SPEEDS)

MIXTURE FLOW [Nmc/h per burner meter]

SURFACE TENSION [dynes/cm] according to ASTM D2578

- v 150m/min
- v 200m/min
- v 250m/min
- v 300m/min
4.4 FLAME TREATMENT MAIN PROCESS PARAMETERS

TREATMENT LEVEL vs. MIXTURE FLOW CURVES (AT DIFFERENT LINE SPEEDS)
4.5 FLAME TREATMENT MAIN PROCESS PARAMETERS

B) MIXTURE COMPOSITION

\[ \phi = \text{EQUIVALENCE RATIO} \]

\[ \lambda = \text{LAMBDa} = \frac{1}{\phi} \]
4.6 FLAME TREATMENT MAIN PROCESS PARAMETERS

"FLAME TEMPERATURE" ANALYZER AND AIR/GAS RATIO CONTROL
4.7 FLAME TREATMENT MAIN PROCESS PARAMETERS

TREATMENT LEVEL vs. JONO TEMPERATURE CURVE (Q_{mix} = 48 m^3/h/m; gap 4.0 mm; s 160 m/min; H_2O roll = 27°C)
4.8 FLAME TREATMENT MAIN PROCESS PARAMETERS

Lambda value vs. Room Temperature at different relative humidity values.

Natural Gas combustion (d=0.59).
Stoichiometric at 20°C; H% = 0
4.9 FLAME TREATMENT MAIN PROCESS PARAMETERS

C) AIR GAP

AIR GAP OPTIMIZATION CURVE
(METHANE 2.5 GAS;
MIXTURE LAMBDA 1.028; GRID TYPE 0)
4.10 FLAME TREATMENT MAIN PROCESS PARAMETERS

FLAME TEMPERATURE vs. AIR GAP at different mixture compositions

![Graph showing FLAME TEMPERATURE vs. AIR GAP at different mixture compositions with curves for LAMBDA 1.000, LAMBDA 1.050, and LAMBDA 0.950.](image)
4.11 FLAME TREATMENT MAIN PROCESS PARAMETERS

D) TREATER ROLL TEMPERATURE

\[ P = KA \Delta T \; \text{[W/m]} \]

\[ K \; \text{[W/(m}^2/°C)] \]

\[ A \; \text{[m}^2] \; \Delta T \; [°C] \]

\[ \frac{1}{K} = \frac{S}{(A \times \lambda_m)} + \frac{1}{h} + R_d \]
5.1 FLAME TREATMENT APPLICATIONS

BOPP Films for Printing and Lamination

- Slip agents – Amides
- Anti-static – Tertiary Ethoxilated Amines
- Anti-static – GMS
- Anti-blocking particles (mineral or polymer)

Layer “A” – Heat Seal / Conversion
Layer “B” – PP Structural
Layer “C” – Heat Seal
5.2 FLAME TREATMENT APPLICATIONS

BOPP Films for Printing and Lamination

NO ADHESION PROMOTER

Corona treated. Slow peeling.

Flame treated. Slow peeling.

Corona treated. Fast peeling.

Flame treated. Fast peeling.

AIMCAL FALL CONFERENCE - MYRTLE BEACH - SC - USA - 19 October 2005
5.3 FLAME TREATMENT APPLICATIONS

BOPP Films for Printing and Lamination

CORONA TREATED

<table>
<thead>
<tr>
<th>Legends</th>
<th>Nr</th>
<th>Fmax (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>695.44</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>536.86</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>778.02</td>
</tr>
</tbody>
</table>

Series graphics:
5.4 FLAME TREATMENT APPLICATIONS

BOPP Films for Printing and Lamination

FLAME TREATED

Series graphics:
5.5 FLAME TREATMENT APPLICATIONS

Metallized Coex films

- Anti-blocking particles
- Al layer (deposition under vacuum)
- Layer “A” – Al deposition receptive
- Layer “B” – PP Structural
- Layer “C” – Heat Seal
5.6 FLAME TREATMENT APPLICATIONS

Metallized Coex films

![Graph showing WVTR (90% RH, 38°C) for different treatment methods.]
5.7 FLAME TREATMENT APPLICATIONS

Metallized Coex films

METAL ADHESION

POLARIZED FLAME TREATED FILMS SHOW 50 TO 100 G/inch HIGHER LAMINATION BOND STRENGTH THAN CORONA TREATED FILMS
5.8 FLAME TREATMENT APPLICATIONS

Sealable Coex films

Targets
Effective treatment at high line speeds, with little impact in heat seal initiation temperature (SIT), on optical properties and flatness

Results
Treated film UT/UT sealing temp = Untreat UT/UT; UT/T and T/T sealing temp. max 10°C > UT/UT . UT = untreated; T = treated .
## 5.9 FLAME TREATMENT APPLICATIONS

### Sealable Coex films

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixt. [m³/h*m]</td>
<td>25</td>
<td>27</td>
<td>28</td>
<td>36</td>
<td>39</td>
<td>28</td>
</tr>
<tr>
<td>Gap [mm]</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.8</td>
<td>3</td>
<td>2.5</td>
</tr>
<tr>
<td>T Jono [°C]</td>
<td>815</td>
<td>815</td>
<td>815</td>
<td>815</td>
<td>825</td>
<td>815</td>
</tr>
<tr>
<td>Speed [m/min]</td>
<td>325</td>
<td>325</td>
<td>325</td>
<td>325</td>
<td>325</td>
<td>325</td>
</tr>
<tr>
<td>Roll Temp.[°C]</td>
<td>19</td>
<td>19</td>
<td>26</td>
<td>19</td>
<td>26</td>
<td>19</td>
</tr>
<tr>
<td>Dynes/cm</td>
<td>41</td>
<td>41</td>
<td>42</td>
<td>43</td>
<td>44</td>
<td>42</td>
</tr>
<tr>
<td>Film aspect (stripes)</td>
<td>N</td>
<td>N</td>
<td>Light</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Curling</td>
<td>N</td>
<td>N</td>
<td>v.little</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Seal Str.[N]</td>
<td>454.8</td>
<td>414.8</td>
<td>147</td>
<td>87.1</td>
<td>77.5</td>
<td>363.9</td>
</tr>
</tbody>
</table>
5.10 FLAME TREATMENT APPLICATIONS

Sealable Coex films

SEALING STRENGTH vs. FLAME TREATMENT PARAMETERS

Mixture flow values [Nm3/h]

Sealable Coex films

AICMAL FALL CONFERENCE - MYRTLE BEACH - SC - USA - 19 October 2005
5.11 FLAME TREATMENT APPLICATIONS

White Opaque films / Synthetic Paper

Targets

Effective treatment at high line speeds, with little effect on optical properties and flatness.

Results

Treatment level up to 44 dynes/cm at 450m/min without problems as stripes along film width and curling effect.
## 5.12 FLAME TREATMENT APPLICATIONS

### White Opaque films / Synthetic Paper

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixt. [m³/h*m]</td>
<td>50</td>
<td>35</td>
<td>40</td>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td>Gap [mm]</td>
<td>3.3</td>
<td>2.5</td>
<td>2.8</td>
<td>2.5</td>
<td>2.8</td>
</tr>
<tr>
<td>T Jono [°C]</td>
<td>815</td>
<td>815</td>
<td>815</td>
<td>820</td>
<td>820</td>
</tr>
<tr>
<td>Speed [m/min]</td>
<td>280</td>
<td>280</td>
<td>280</td>
<td>280</td>
<td>280</td>
</tr>
<tr>
<td>Roll Temp.[°C]</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Dynes/cm</td>
<td>50</td>
<td>42</td>
<td>46</td>
<td>42</td>
<td>44</td>
</tr>
<tr>
<td>Film aspect (stripes)</td>
<td>2/3</td>
<td>1/2</td>
<td>2</td>
<td>0/1</td>
<td>1</td>
</tr>
<tr>
<td>Curling</td>
<td>1/2</td>
<td>1</td>
<td>1/2</td>
<td>0/1</td>
<td>0/1</td>
</tr>
</tbody>
</table>

AIMCAL FALL CONFERENCE - MYRTLE BEACH - SC - USA - 19 October 2005
5.13 FLAME TREATMENT APPLICATIONS

esseCI SRL PILOT PLANT
esseCl in the World
Countries of Customers
BACK TO LIST