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ENERGY INTENSITY LOWERING IN POLYETHYLENE PRODUCTION

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ABSTRACT
World production of polyethylene production 2004 was over 50 million tons with value of 60 billion US dollar. In order to keep pace with trend on competitive world market, lowering product cost is the most important. Energy costs make their significant share. In this paper energy analysis of polyethylene production is analysed. Based on process data flue gases heat recovery in order to lower energy intensity is proposed. For instance to produce 1 kg of high density polyethylene (HDPE) 3005,5kJ of energy is required. In case of flue gases waste heat recovery this amount of energy can be lowered for 335,3kJ/kg$_{HDPE}$ or 11,2%.
Keywords: HDPE production, waste heat, flue gases recovery

1. INTRODUCTION
High **D**ensity **P**oly**E**thylene (HDPE) is among most important polymers in the world. In 2004 production of HDPE on global level was 25 million tons with estimated value of 29 billion US dollars [1]. At the same time production of LDPE (Low Density PolyEthylene) and LLDPE (Linear Low Density PolyEthylene) was 19 and 16 million tons respectively, with market value of 22 and 17 billion US dollars each.. Applications of polyethylene products are various. LDPE is widely used for making films for food and non food packaging, for coating paper and paperboard products for liquid food products packaging etc. LLDPE is also used for films, but of lower thickness compared to LDPE. HDPE is widely used for blow and injection molding. This group of plastics has the same repeating unit $(CH_2)_n$ creating large macromolecules but with different structures determining their physical and chemical properties and finally their use. HDPE, as main issue in following analysis, has density 0,940 g/cm^3 and over [2, 3].

2. HDPE PRODUCTION AND ENERGY CONSUMPTION
The history of HDPE is very long, from the end of nineteenth century, but first commercial technologies emerged in early 50's of last century and came by Phillips Petroleum Co. in United States and Hoechst in West Germany [2]. Slurry or suspension process, the oldest and most widely

used polymerization process [2], is shown on Figure 1., together with relevant energy and mass flows. Process steam parameters are given in Table 1 [4].

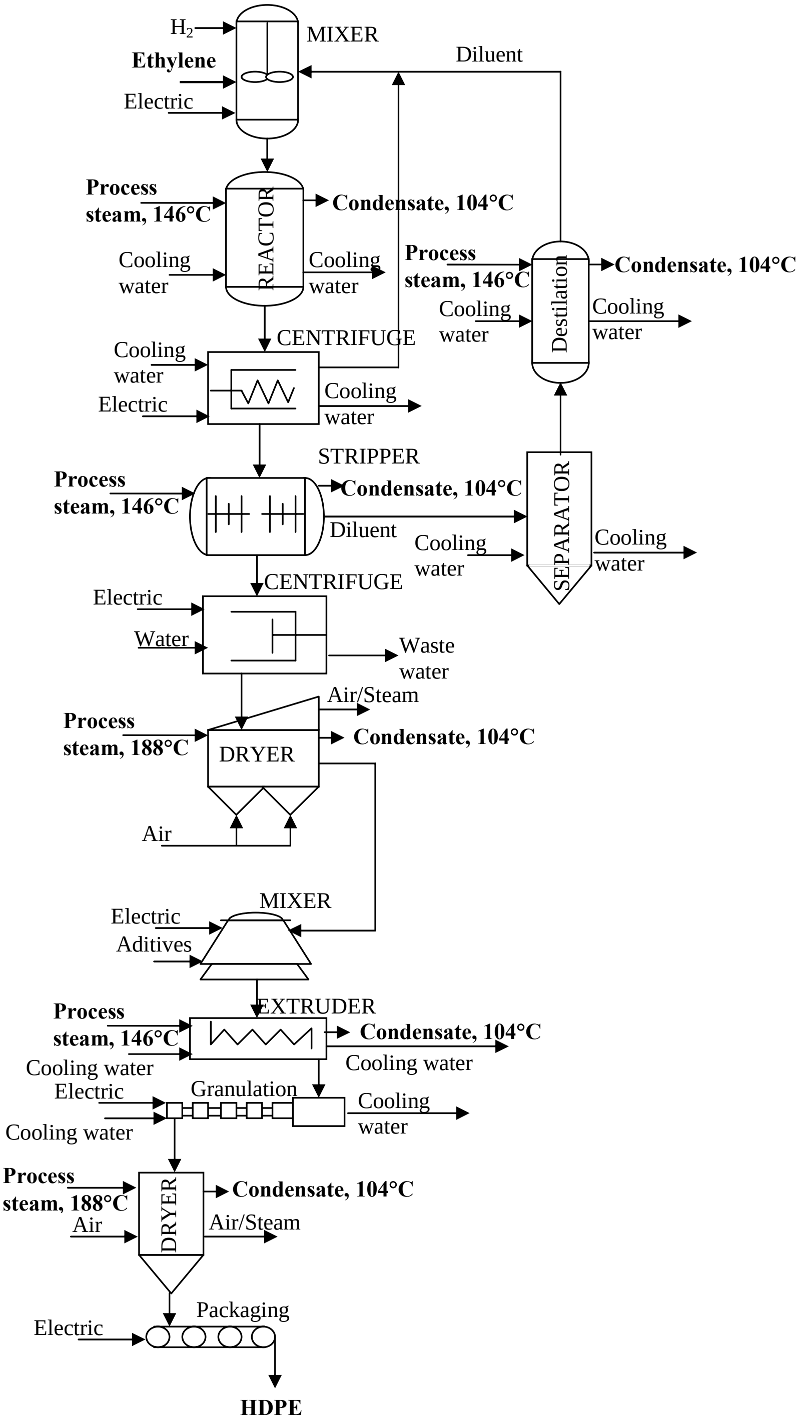

Figure 1. Scheme of HDPE slurry production process

Table 1. Process data for HDPE slurry process

Process steam		
Temp., $^{\circ}$C	Rate, d_S, $\mathrm{kg/kg_{LDPE}}$	Specific energy, e, $\mathrm{kJ/kg_{LDPE}}$
187,8	0,300	840,5
146,1	0,820	2266,8

Process steam of 12,5 bar and temperature 187,8°C is produced in boiler fired by natural gas with lower heating value H_L=35507 $\mathrm{kJ/m^3}$. Process heat energy and natural gas consumption required for producing mass unit of HDPE can be calculated from following equations:
The equations and formulas should be written and numbered as follows:

$$q_S = d_S \cdot (h_S - h_W) = 3005{,}5\ \mathrm{kJ/kg_{HDPE}}\ . \quad \text{... (1)}$$

$$V_F = \frac{d_S \cdot (h_S - h_W)}{H_L \cdot \eta_B} = 0{,}121\ \mathrm{m^3/kg_{HDPE}}\ . \quad \text{... (2)}$$

where are:
- $h_S = 2784\ \mathrm{kJ/kgK}$ – enthalpy of process steam, $h_W = 100{,}5\ \mathrm{kJ/kgK}$ – enthalpy of fresh water,
- d_S, $\mathrm{kg/kg_{HDPE}}$ – steam rate and $\eta_B = 70\%$ – boiler efficiency.

Flue gases analysis gave volume of flue gases' constituents per mass unit of HDPE (Table 2.). These values are necessary for energy saving analysis in next chapter

Table 2. Volume of flue gases in HDPE production

Flue gases volume, $\mathrm{m^3/kg_{HDPE}}$				
V_{CO_2}	V_{N_2}	V_{H_2}	V_{O_2}	V_{FG}
0,121	1,090	0,243	0,048	1,502

3. FLUE GASES HEAT RECOVERY

Since energy consumption lowering is of major concern in each industrial process, the same is in case HDPE production. One of common and efficient options is flue gases waste heat recovery [5] Argument for this option is found in high outlet temperature of flue gases leaving boiler. This energy potential can be used for air preheating. Scheme of proposed solution is given in Figure 2. Flue gases before being rejected to atmosphere are cooled down in air preheater by inlet stream of fresh air entering combustion space in boiler.

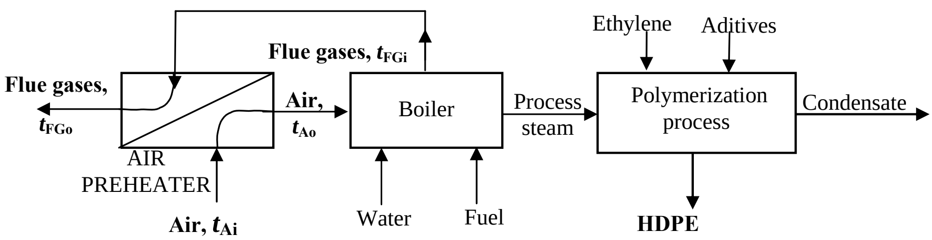

Figure 2. Scheme of flue gases waste heat recovery in HDPE slurry production process

For proposed scheme heat balance for air preheater can be set as follows

$$c_{pFG} V_{FG} \cdot (t_{FGi} - t_{FGo}) = c_{pA} V_A \cdot (t_{oi} - t_{Ai}) = c_{pA} V_A \cdot (t_{FGi} - t_{Ai}) \cdot \eta_{AP} \quad \text{.... (3)}$$

This enables calculating of energy saving potential using following equations and values calculated or defined in previous text. Remaining data are given in Table 3.

Table 3. Temperatures and specific heat values of air and flue gases

	Inlet temperatures	Specific heat
Air	$t_{Ai} = 24^{\circ}\mathrm{C}$	$c_{pA} = 1,298\ \mathrm{kJ/m^3K}$
Flue gases	$t_{FGi} = 232,2^{\circ}\mathrm{C}$	$c_{pFG} = 1,384\ \mathrm{kJ/m^3K}$

Outlet temperature after air of ambient temperature passed air preheater with efficiency $\eta_P = 0,9$ according to [6] is

$$t_{Ao} = t_{Ai} + \left(t_{FGi} - t_{Zi}\right) \cdot \eta_{AP} = 211,4^{\circ}\mathrm{C} \qquad \text{... (4)}$$

Outlet temperature of flue gases after being chilled in air preheater with air volume (from stoichiometric relations) $V_A = 0,1892\ \mathrm{m^3/kg_{HDPE}}$:

$$t_{FGo} = t_{DPi} - \frac{c_{pA} \cdot V_A}{c_{pFG} \cdot V_{FG}} \cdot \left(t_{FGi} - t_{Ai}\right) \cdot \eta_{AP} = 70,9^{\circ}\mathrm{C}\,. \qquad \text{... (5)}$$

Heat energy exchanged in air preheater and at same time energy saving due to flue gases waste heat reuse is:

$$q_{FG} = c_{pFG} \cdot V_{FG} \cdot \left(t_{FGi} - t_{FGo}\right) = 335,3\ \mathrm{kJ/kg_{HDPE}}\,. \qquad \text{... (6)}$$

or expressed in volume of natural gas saved:

$$V_{FFG} = \frac{q_{FG}}{H_L \cdot \eta_B} = 0,0135\ \mathrm{m^3/kg_{HDPE}}\,. \qquad \text{... (7)}$$

Percentage of energy saving follows from equations (1) and (6):

$$\Delta q_{FG} = \frac{q_{FG}}{q_S} \cdot 100\% = 11,2\%\,. \qquad \text{... (8)}$$

4. CONCLUSION

Energy intensity of various polyethylenes is more result of huge quantities produced than of energy consumption per mass unit. Presented analysis of high density polyethylene (HDPE) production by slurry process method shown significant waste heat potential of flue gases. Proposed scheme for their reuse in way of combustion air preheating in air preheater points that energy i.e. natural gas saving is up to 11,2%. There are two main issues of achieved saving, first energy cost is reduced and environmental impact is lowered.

5. REFERENCES

[1] http://www.sriconsulting .com/

[2] Doak, K. W., James, D. E., Beach, D. L., Kissin, Y. V.: Ethylene Polymers in Encyclopedia of Polymer Science and Engineering, Vol. 6, John Wiley&Sons, New York, 1986.

[3] Olmsted, J., Williams, G. M.: Chemistry, The Molecular Science, Mosby, St. Louis, 1994.

[4] Process data, personal communication, 2002.

[5] De Beer, J.: Potential for Industrial Energy-Efficiency Improvement in the Long Term, Kluwer Academic Publishers, Dordrecht, 2000.

[6] Eastop, T. D., McConkey, A.: Applied Thermodynamics for Engineering Technologists, Longman Scientific & Technical, New York, 1993.