# TRIBOLOGICAL ECONOMICS OF CERAMIC PRODUCTION

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## 1. INTRODUCTION

Ceramic tile production – raw materials, competitiveness, energy and ecological effectiveness are discussed from a tribological[1] economics point of view. This is based on the contact interaction, direct attitude to the production, quality and design of the tiles and their consumption behaviour. Contacts, contact phenomena and processes are represented in space marked by the vertexes, faces, and volume of a tetrahedron [6,10].

## 2. CERAMIC RAW MATERIALS

Economic production Q is a function of the production factors $R_n$-natural resources, L-labour (human resources) and C-capital [12]: **Q =** f ($R_n$, L, C) or **Q =** f ($R_n$, L+C) at equal L and C growth and constant correlation L/ Q or (L + C)/ Q (Fig. 1,a). Due to the heterogeneous character of the natural raw materials, **Q =** f [$R_n$, L+C, Δ (L + C)]. The heterogeneous resources $R_u$ in the function in combination with supplementary labour and capital Δ (L + C) form the homogeneous resources $R_n$: $R_n = R_u + \Delta (L + C)$ (Fig. 1,b). The balanced raw materials $R_b$ for the eco-compatible materials saving economics are based on the recycled $R_r$ and partly on the synthetic $R_s$ raw materials, but the natural raw materials $R_n$ are only used for replenishment of the production and recycling losses: $R_b = R_r + R_s + R_n$, where $R_r > R_s > R_n$ (Fig. 1, c).

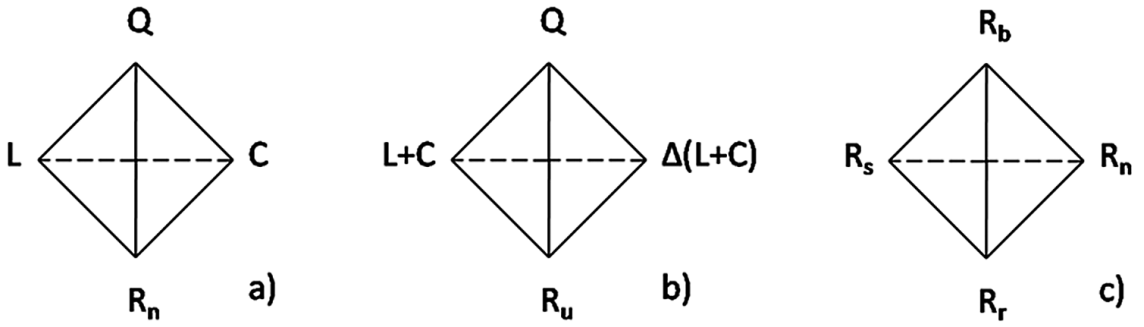


*Fig. 1. Productive output Q at homogeneous (a) and heterogeneous (b) raw materials; balanced raw materials (c).*

1 Tribology, as an interdisciplinary science on friction, lubricating and wear, studies all contacts, contact interaction and phenomena in nature, techniques and society [10].

## 3. COMPETITIVENESS AND NATURAL PROTECTION STRATEGY OF COMPANY

The balance between a company's interest (high quality of production; decrease of losses and prime cost; stabilization of market positions and market segments) and society interests (certification authorities; ecological control; anti-monopoly service) is achieved by investments in reconstruction and production expansion, and innovations in technology and management [15].

Ceramic firms compete on the basis of their industrial products. Ceramic product competitiveness in market economy conditions, i.e. their ability to realize more profit in comparison to others, depends on the business climate and company and company management quality [8]. Taking into account the law for contact interaction [10] a graphic dependence is presented in Figure 2, geometrically displayed by the vertexes of a tetrahedron, along the chain: balance raw material (recycled, synthetic, natural) – the best available technology (natural protection investments, innovations, know-how) – eco-ceramic products (quality and security of product, prime cost, losses) – competitiveness and natural protection strategies of the firm (eco-tribological marketing, eco-tribological firm management). Quality and ecological safety of the ceramic product, as well as the decrease of its prime cost and losses are a function of the best available technology; of nature protection investments; from the innovation and know-how; from the bigger part of the recycled resources (own or from other companies) in comparison to the natural, thus closing the production cycle.

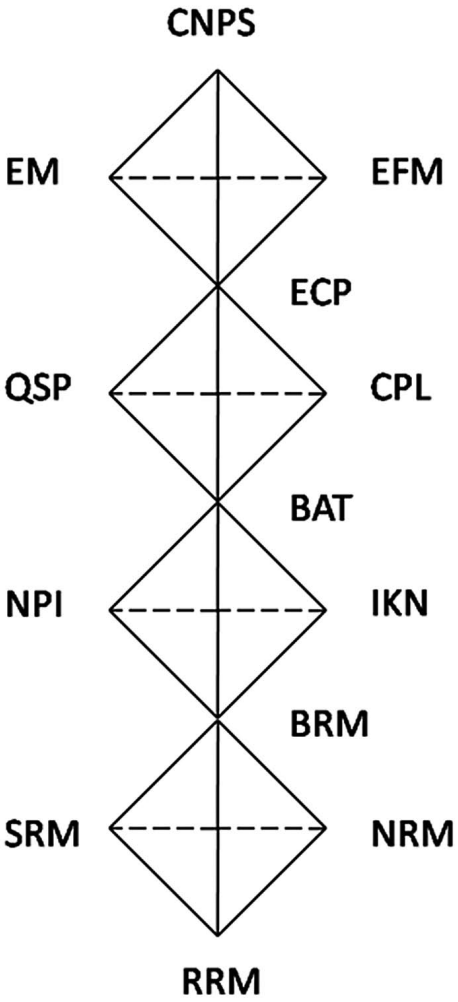


*Fig. 2. Competitiveness and natural protection strategy of a firm (CNPS): recycled raw material (RRM); synthetic raw material (SRM); natural raw material (NRM); balance raw material (BRM); natural protection investments (NPI); innovations, know-how (IKH); best available technology (BAT); quality and security of product (QSP); prime cost, losses (CPL); eco-ceramic product (ECP); eco-tribological marketing (EM); eco-tribological firm management (EFM).*

## CERAMIC TILES FROM INDUSTRIAL WASTES

Recycled ceramic resources from industrial wastes are for instance calumite [14] and SLS (soda-lime-silica) glass [9]. An example of ceramic tiles from recycled industrial wastes is "Ecolite" tiles [11]. Calumite is blast furnace slag with low content of ferrous oxides, with application in glass industry and ceramics, and recycled SLS glass cullet – as a flux in ceramics.

Ceramic tiles are prepared from water-granulated blast furnace slag calcined at 1000–1100$^0$C (1h) (Kremikovtsi, Sofia) [2]; flotation waste from copper ore (Varli bryag, Bourgas) [3]; marble powder, waste from marble treatment (Malko Tarnovo) [1]; carbonate waste from sugar production (Kameno, Bourgas)[5] and waste from glost-fired faience tiles (Isperih) [4]. Firing of tiles is conducted in a factory: biscuit fired at 1060–1085$^0$C and glost-fired at 950–1000$^0$C (Table 1.).

| Ceramic tiles | Ceramic mass, wt% | $S_f$, % | WA, % | $\sigma_b$, MPa |
|---|---|---|---|---|
| With calcined blast furnace slag | 50 slag + 20 raw kaolin + 30 plastic clay | 0,45 | 15,56 | 28,5 |
| With flotation waste from copper ore | 50 waste + 20 raw kaolin + 30 plastic clay | 2,97 | 7,50 | 31,8 |
| With marble powder (waste) | 15 marble powder + 70 clay material + 3 dolomite + 12 reject | | 13,80 | 23,1 |
| With carbonate waste | 10 carbonate waste + 30 perlite + 60 refractory clay | 1,79 | 12,34 | 30,0 |
| With waste from glost-fired faience tiles | 9 faience waste + 69 clay material + 16 dolomite + 6 limestone | 0,49 | 14,32 | 26,2 |

*Table 1. Shrinkage ($S_f$), water absorption (WA) and bending strength ($\sigma_b$) of ceramic tiles*

Water-granulated blast furnace slag calcined at 1000–1100$^0$C (1h) is compared to calumite; ground glost waste from faience production – with SLS glass, and the prepared ceramic tiles from calcined blast furnace slag – with "Ecolite" tiles. The calcined blast furnace slag, obtained only from melilite, similarly to wollastonite [13], is a suitable resource for fast single firing of ceramic masses.

## CONCLUSION

Tribological economics (tribological management and tribological marketing) helps spatial presentation of contact interactions and phenomena following ceramic production: resource – technology – industrial product or raw material – technology – industrial product – consumption. The accent is on the recycled resources (own or from other productions) as substitutes of natural resources.

Water-granulated blast furnace slag calcined at 1000–1100$^0$C (1h) and ground waste from glost firing of faience tiles are suitable recycled resources for the production of ceramic tiles. Blast furnace slag (up to 70 wt%), built only by melilite and faience tiles glost waste (up to 10 wt%) are recommended as a part of the body composition for fast firing.

Bulgarian industrial wastes [7], as technogenic raw materials, provide the possibility of creating small and medium-sized companies for recycling. The cluster form is more suitable for the cooperation of these companies with a leading Bulgarian or foreign company for the production of ceramic tiles.

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