POWER CORRELATION OF DRIVING MOTOR FOR TURBO BLOWER WITH INDUSTRIAL PROCESS REQUIREMENTS

Constantin VÎLCU[1], Filip NICULESCU[1], Andrei MITRU[1], Marian DRĂGHICI[1], Cristian NECHIFOR[1], Mirela-Letiţia VASILE[1]

ABSTRACT: The turbo blowers are high-speed pneumatic bladed machines, great consumers of mechanical work. They are classified within the group of dynamic compressors, used for raising the pressure of gas. The turbo blower can be driven with a high-power three-phase asynchronous motor: 75 kW ÷ 400 kW ÷ 1.2 MW or with a gas turbine engine. Within the industrial process it is used for, the turbo blower becomes an execution element for process control and regulation. The paper presents the computation methodology for the optimum dimensioning of the necessary power for the driving motor of a turbo blower, depending on the requirements of the industrial process. Numerical modelling has been performed for a wide range of pressures and discharge flows that the application may require. The power engine computation program for the turbo blower was realised in Mathcad. The present paper adds novelty by the 3D graphic analysis for the dimensioning of a driving motor of a turbo blower through the NMPTB program elaborated.

KEYWORDS: *turbo blowers, compressed air, centrifugal compressors, numerical modelling*

ABBREVIATIONS
CAE – Computer-Aided Engineering;
NMPTB – Numerical Modelling Program for Turbo Blower;
TB – Turbo Blower.
Note: the other abbreviations are described throughout the paper.

1. INTRODUCTION

The turbo blowers are centrifugal compressors for air or natural gas compression, having a compression ratio of $\boldsymbol{\pi_c} \in \{\mathbf{1.1 \div 2.5}\}$, [1]. TB fit within the category of dynamic compressors that elevate the pressure of the working fluid by the transferring kinetic energy to the gas through the centrifugal forces exerted by a bladed rotor. The kinetic energy of the gas molecules brought into rotation movement is transformed at the level of the compressor stator (diffuser) into potential pressure energy. The process has a continuous operation at different speeds of the TB engine. Choosing a type of compressor for a certain application is realised considering the specific requirements of the industrial process so as to be as performing and efficient as possible for the given application. In this regard, the specifications have to include:

a) general information regarding location (altitude) and process (working fluid quality);
b) average, maximum (peak) and minimum values for pressures and flows of the compressed fluid;
c) the ambient temperature range in the operating location;
d) the temperature range of the cooling fluid (air or water), appropriate for the location;
e) compressor control strategy according to exploitation requirements;
f) maximum noise level accepted at the workstation;
g) number continuous operation hours per year, [2, 3].

Considering the constraining factors above, an optimal choice is realized taking into account compressor's technological features. Centrifugal compressors are capable of delivering air/gas at a flow rate of 1000 ÷ 35000 Nm^3/h, being more frequently used when a demand for high flows arises. These ones are used for flows over 3000 Nm^3/h and axial compressors are used for flows over 35000 Nm^3/h [4]. Several research papers deal with estimating the performances of newly designed turbo blowers, depending on operation conditions, [5, 6, 7].

[1]Romanian **R**esearch and **D**evelopment **I**nstitute for Gas Turbines **COMOTI,** Bucharest, Romania

A new style turbo blower called "air foil bearing-variable speed-single stage turbo blower" […] can reduce power consumption by 20% on average. Reducing the power consumption is required to all industries regardless of its type and scale, [8]. New high speed high performance turbo blowers are developed by [9, 10, 11].

The essential quality indicator for a centrifugal blower is represented by the specific consumption $\boldsymbol{I_{cw}}$ [Wh/Nm^3]. The problem that needs to be solved is to reduce this indicator to an optimum value so that the superior performances regarding flow and pressure to be maintained. Low costs can be thus ensured on TB execution and maintenance. The problem will be analysed for two blowers, [12]:

i. TS 3500-1.6 turbo blower case study with over 20000 operating hours (Figure 1a);
ii. New TS 23000-2.0 high flow turbo blower in CAE stage.

For a preliminary calculation, the immediate ways to solve the problem [13] are:

- determining the calculated power P_{wc} [kW] of the TB drive motor depending on Voh flow [Nm^3/h] and pressure P_r [bara] requirements for the industrial process, with the operation conditions specified in the scope of work;
- valid selection of standardized P_{wn} power [kW] of the three-phase asynchronous motor, to maintain a power reserve R_{pw} [%], enough for a minimum level of installed power P_{wi} [kW] of the TB group;
- increasing TB efficiency, according to the following relation:

$$\boldsymbol{\eta_{ts}} = \boldsymbol{\eta_c} * \boldsymbol{\eta_a} * \boldsymbol{\eta_m} > 0.70 \tag{1}$$

This can be realised by:

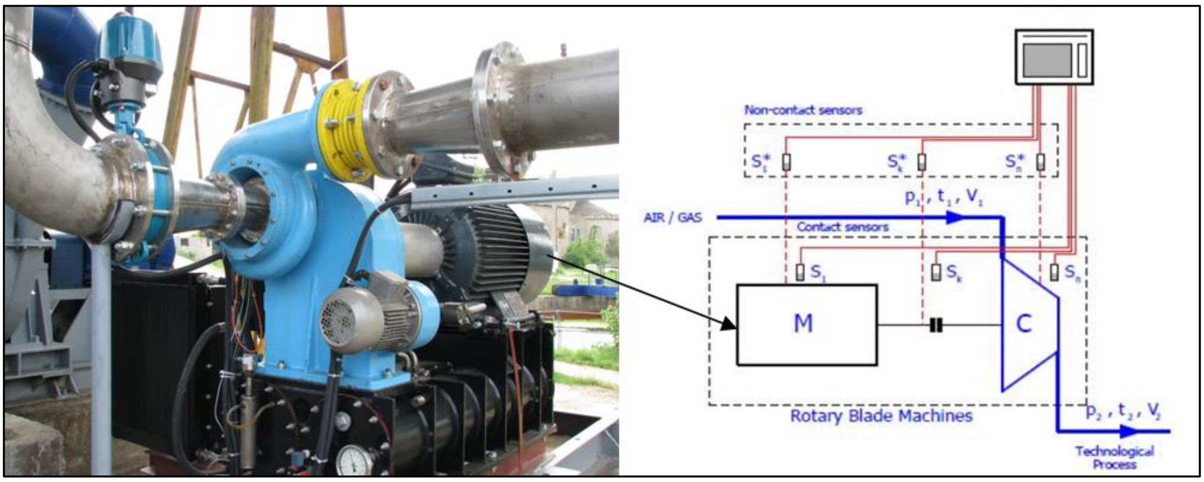
- increasing the efficiency of the compression unit $\eta_c \in (0.77 \div 0.88)$;
- increasing the efficiency of the TB multiplication gear $\eta_a \in (0.9 \div 0.99)$;
- choosing an electric machine with higher efficiency $\eta_m \in (0.85 \div 0.95)$.

At time being, the first two methods will be addressed for solving the studied and analysed cases.

2. METHODOLOGY FOR DIMENSIONING THE DRIVING MOTOR

In this chapter we present the computation methodology for choosing the optimal power of the driving motor for a turbo blower, in correlation with the requirements of the industrial process.

The numerical modelling was performed using Mathcad, for a wide range of pressures and discharge flows that may be required by the industrial application in which the turbo blower is integrated. Figure 1a) shows the TS 3500-1.6 turbo blower located in the wastewater treatment plant Târgovişte and in Figure 1b) presents a schematic diagram of the air compression process for a COMOTI trademarked turbo blower [14].



a) b)

Fig. 1 – a) Turbo blower TS 3500-1.6 and b) Schematic diagram of the air compression process

2.1. Case study for turbo blower TS 3500-1.6, driving motor dimensioning check-up

Determining the electrical power of the driving motor of the turbo blower is realized in correlation with the requirements of the process for which the TB is used for, specified in the scope of work for the given application type. Thus, for the following operation domain imposed to TS 3500-1.6 turbo blower:

$$\boldsymbol{\mathcal{L}(Voh,\ \pi c)} \equiv (3500,\ 1.6)\ \ [\text{Nm}^3/\text{h}, \#] \tag{2}$$

the air weight flow *Gas* at the turbo blower inlet, depending on the inlet air temperature *Tas*, and the location altitude *Hs*, is given by the relation:

$$\boldsymbol{Gas(Tas, Hs) = Vos * \rho h(Tas, Hs) = Vos * \frac{Po}{Ra*Tas} * e^{-\frac{M*g*Hs}{R*Tas}}}\ \ [\text{kg/s}] \tag{3}$$

where the air volume flow per second *(Vos)* is given by the imposed hourly volume flow *(Voh)*:

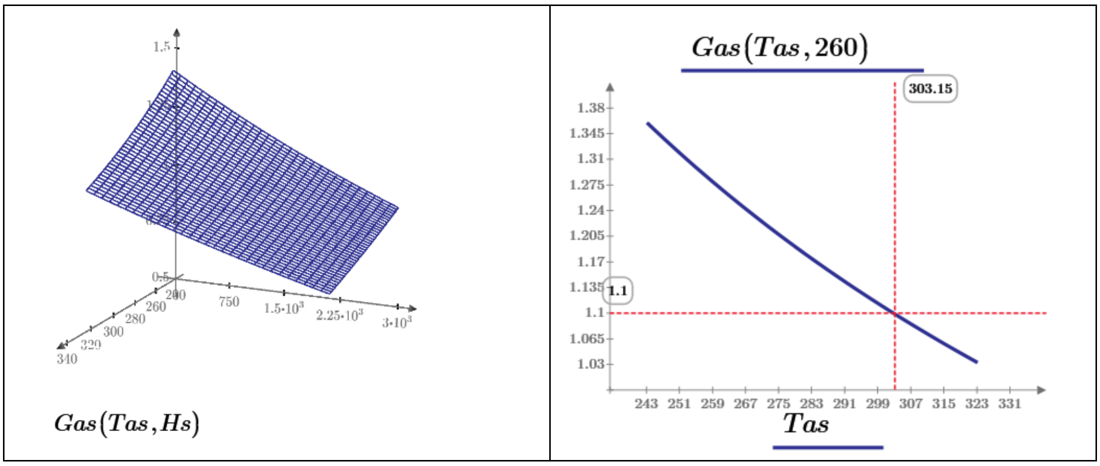
$$\boldsymbol{Vos = \frac{Voh}{3600}} = 0.972\ \ [\text{Nm}^3/\text{s}] \tag{4}$$

and the air density ρh in the given location depends on the temperature variation in the ambient environment *Tas* and on the atmospheric pressure at the altitude *Hs* in the location where the TB is installed.

For the following values of the constants: *Po* = 101325 [Pa]; *To* = 273.15 [°K]; *Ra* = 287.19 [J/kg*K]; *M* = 0.029 [kg/mol]; *g* = 9.81 [m/s^2]; R = 8.31 [J/mol*K] and the variation domains of variables: $Tas = 243.15 \div 323.15$ [°K] and $Hs = 0, 100 \div 3000$ [m], the variation of the air weight flow function *Gas* at TB inlet, given by equation (3), is represented graphically in 3D coordinates in Figure 2a). For operation location altitude *(Hs = 260 m)*, the variation of *Gas(Tas, Hs)* function of temperature is represented graphically in 2D coordinates in Figure 2b).

Considering the numerous factors which lead to increasing the operation temperature (high ambient temperatures during summer, direct sunlight, heat generating equipment in proximity, etc.), it is recommended that a heavy duty rate of the turbo blower to be chosen for a continuous operation (S1) of the driving motor. This is due to the high temperatures on the inlet. For an average value *Gam* in Figure 2b) considered for inlet air weight flow, correlated with the operation conditions in situ, we have:

$$\boldsymbol{Gam} = \boldsymbol{Gas}(303.15,\ 206) = 1.099\ [\text{kg/s}] \tag{5}$$



a) b)

Fig. 2 – a) Variation of air weight flow at TB inlet function of temperature (Ox) and altitude (Oy); b) Variation of air weight flow at inlet function of temperature, for TS 3500-1.6

For TS 3500-1.6, we calculate the efficiency of the TB compression group, with relation (1), to be:

$$\boldsymbol{\eta_{ts}} = 0.83 * 0.98 * 0.92 = 0.748 \tag{6}$$

For a polytropic state transformation of compressed air *(k=1.4)*, the driving motor power for the turbo blower is calculated with the relation:

$$\boldsymbol{Pcw = Gam * (\frac{k}{k-1} * Ra * Tam * (\pi c^{\frac{k-1}{k}} - 1)) * \frac{10^{-3}}{\eta ts}} = 66.666\ \ [\text{kW}] \tag{7}$$

The numerical modelling program NMPTB for the dimensioning of the driving motor enables the graphic visualisation of the compressor shaft power *Pc*, as well as the minimum power *Pw* necessary for the driving motor, considering the given application. The variation of these powers in [kW] with the suction air temperature *Tas* is represented in Figure 3.

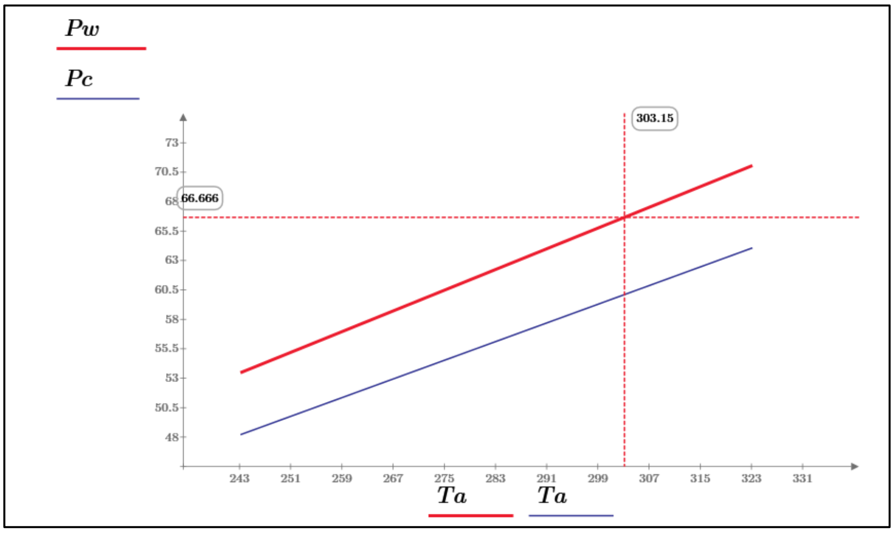


Fig. 3 – Variation with temperature *Ta* of driving motor power of *TS 3500-1.6* (*Pc* [kW] – power at compressor shaft; *Pw* [kW] – motor power)

The standardized domain regarding manufacturing electrical power [kW] of three-phase asynchronous motors, in which *Pcw* is inserted for comparison regarding choosing the driving motor for TB is presented in the vector with the values of nominal powers *Pwn* below:

$$\boldsymbol{Pwn} = [75; 90; 110; 132; 160; 200; 250; 315; 355; 400; 450; 500; 550; 630; 710; 800; 1000] \quad (8)$$

From the vector above, it is chosen the electrical power from the immediately superior class to the calculated value *Pcw*. The difference between *Pwn* and *Pcw* will be the power reserve for the electrical machine operation. For an optimal selection of the motor, the power reserve *δP* is recommended to be within the interval of (5÷15)% from the nominal power *Pwn.* According to the value resulted in the previous programming sequence for *Pcw*, we calculate with the presented algorithm:

$$\boldsymbol{n = 5} \;\triangleright\; \boldsymbol{Pwn_{0,n}} = 75 \;\text{[kW]}; \qquad \boldsymbol{\delta P = Pwn_{0,n} - Pcw} = 8.334 \;\text{[kW]} \quad (9)$$

Consequently, the following values result:

$$\boldsymbol{Rpw = 100} * \frac{\boldsymbol{\delta P}}{\boldsymbol{Pwn_{0,n}}} = 11.11 \;[\%] \quad (10)$$

$$\boldsymbol{Wms = 100} * \frac{\boldsymbol{Pcw}}{\boldsymbol{Pwn_{0,n}}} = 88.89 \;[\%] \quad (11)$$

$$\boldsymbol{Icw = 1000} * \frac{\boldsymbol{Pcw}}{\boldsymbol{Voh}} = 19.047 \;[\text{Wh/Nm}^3] \quad (12)$$

Based on the results obtained, it can be stated that the turbo blower *TS 3500-1.6* has been properly dimensioned with regard to the driving motor, due to the following reasons:

- By choosing a motor with nominal power $Pwn_{0,n} = 75$ [kW], the efficiency of the turbo blower group is of $\eta_{ts} = 0.748$ and the compression ratio is of $\pi c = 1.6$, thus ensuring the necessary discharge air flow of $Voh = 3500$ [Nm3/h] for wastewater biological (aeration) treatment;
- Loading the motor at only $Wms = 88.89$ % of the nominal power enables the turbo blower to be used successfully in heavy-duty operation conditions or to be used for a wide range of the technological processes in the application category it was designed for;
- The quality indicator (technical and economical) $Icw = 19.047$ [Wh/Nm3] of *TS 3500-1.6*, compared with the one of same class turbo blowers but of different trademark, indicates an optimal selection (quality/price) of the driving motor for our turbo blower.

2.2. Driving motor dimensioning for high flow turbo blower TS 23000-2.0

It is proceeded directly to step #3 of NMPTB program. The calculated power of the driving motor for the turbo blower, given by relation (7), is written as a function of three variables *Pcw*(*πc, Vos, Ta*):

$$\boldsymbol{Pcw(\pi c, Vos, Ta) = Vos * \rho am * (\frac{k}{k-1} * Ra * Ta * (\pi c^{\frac{k-1}{k}} - 1)) * \frac{10^{-3}}{\eta ts}} \quad [\text{kW}] \qquad (13)$$

where we have:

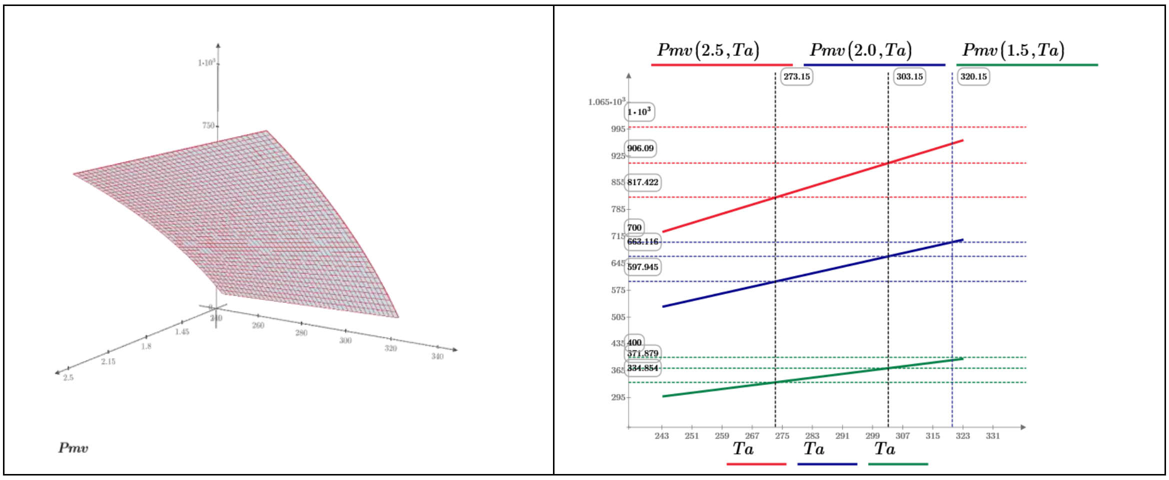
- TB compression ratio vector: $\pi c = 1.100 \div 2.500$ [#]
- TB hourly discharge flow vector: $Voh = 1000 \div 25000$ [Nm3/h]
- Inlet air temperature vector: $Ta = 243.15 \div 323.15$ [°K]

and parameter values: $\{k, Ra, \rho am, \eta ts\} = \{1.4;\ 287.19; 1.164; 0.748\}$
were established in the previous step of NMPTB program, according to the process.

For an imposed hourly volume flow of TB: $Voh = 23\,000$ [Nm^3/h], the function *Pcw*($\pi c, Vos, Ta$) given by relation (13) becomes:

$$\boldsymbol{Pmv(\pi c, Ta) = \frac{Voh * \rho am}{3600} * (\frac{k}{k-1} * Ra * Ta * (\pi c^{\frac{k-1}{k}} - 1)) * \frac{10^{-3}}{\eta ts}} \quad [\text{kW}] \qquad (14)$$

The variation graph in 3D coordinates of motor power $Pmv(\pi c, Ta)$ [kW] function of variables πc (Ox) and Ta (Oy) is presented in Figure 4a). The curved mesh nodes from the spatial surface domain represent the values for calculated power of the driving motor, necessary for obtaining the state vectors (*p*,*V*,*T*) of the industrial process. For *TS 23000* turbo blower model [Nm^3/h], presently in CAE stage, the values of calculated power are analysed for three representative nodes from the illustrate domain. These ones correspond to the values of compression ratio $\pi c \in \{1.5;\ 2.0;\ 2.5\}$ and are represented in Figure 4b).



a) b)

Fig. 4 – a) 3D variation graph for the power [kW] of driving motor for *TS 23000* and b) Variation of motor power *Pmv* [kW] with temperature *Ta* at constant *πc*

According to the values calculated for driving motor power in (14), the following nominal powers *Pwn* will result, corresponding to the imposed compression ratio:

$$Pmv(1.5, 303.15) = 371.879\ [\text{kW}] \Rightarrow Pwn_{0,14} = 400\ [\text{kW}] \qquad (15)$$

$$Pmv(2.0, 303.15) = 663.116\ [\text{kW}] \Rightarrow Pwn_{0,19} = 710\ [\text{kW}] \qquad (16)$$

$$Pmv(2.5, 303.15) = 906.09\ [\text{kW}] \Rightarrow Pwn_{0,21} = 1000\ [\text{kW}] \qquad (17)$$

In the graphs showing the variation of Pmv with TB inlet air temperature for the three compression ratios πc analysed, the power reserves ensured by nominal powers can be easily identified through markers.

The synthesis matrix *Mts* of turbo blower *TS 23000-πc* is composed of the following columns: *Voh* [Nm3/h], *πc* [#], *Pcw* [kW], *Pwn* [kW], *Rpw* [%], *Wms* [%], *Icw* [Wh/Nm^3].

The data which has been previously processed by successive iterations was inserted in the matrix *Mts* below for the analysis of the quality indicator *Icw:*

$$Mts = \begin{bmatrix} 23000 & 1.5 & 371.88 & 400 & 7.03 & 92.97 & 16.169 \\ 23000 & 2.0 & 663.116 & 710 & 6.60 & 93.40 & 28.831 \\ 23000 & 2.5 & 906.09 & 1000 & 9.39 & 90.61 & 39.395 \end{bmatrix} \quad (18)$$

It can be observed that the numerical value of the quality indicator *Icw* [Wh/Nm^3] for *TS 23000-πc* increases with the compression ratio πc within the acceptable limits of specific consumption.

3. CONCLUSIONS

The elaborated article confirms that the three-phase asynchronous motor of 75 kW (400 V, 50 Hz) which equips the turbo blower model *TS 3500-1.6* is dimensioned according to the specified requirements in the scope of work for the industrial process. The turbo blower ensures, at a compression ratio of 1.6, the discharge air flow of 3500 [Nm^3/h] necessary for the wastewater biological treatment process. The specific consumption of 19.047 [Wh/Nm^3] indicates an optimal choice of the driving motor.

For the turbo blower model *TS 23000-*π_c, depending on the compression ratio π_c, the power of the driving motor is selected from the domain of 400 kW ÷ 1.2 MW. For these TB driving motors within 1 MW category, it is recommended a medium power supply system of 6 kV. The specific consumption increases with the compression ratio π_c and implicitly with the installed power of the electrical machine. A low value of *Icw* [Wh/Nm^3] is obtained especially by increasing the overall efficiency of the TB group.

ACKNOWLEDGEMENT

This paper was elaborated through Nucleu TURBO 2020 program, conducted with MCI support, project PN 16.26.03.01. We would like to thank the program manager, PhD eng. Romulus Petcu, for the support provided for the good deployment of R&D activities within the project.

REFERENCES

[1] ISO/TC118/SC1, " *Compresseurs de procede*"; ISO 5389:2005, "*Turbocompresseurs - Code d'essais des performances*", 2018, https://www.iso.org/fr/committee/51866.html;
[2] Michel HIRAUX, "*Air comprimé*", ELLIPSE – ISE, D140403A, Marche-Lez-Ecaussinnes, 2014;
[3] Raluca MOCANU, *„Cercetari teoretice şi experimentale asupra echipamentelor cu maşini paletate destinate protecţiei mediului"*, INCD Turbomotoare - COMOTI, Program NUCLEU, Bucureşti, 2009;
[4] IFP ENSPM, "*COMPRESSEURS – Tehnologie et fonctionnement des compresseurs",* MT COM - 01888_B_F - Rév. 2, Formation Industrie, Paris, 2005;
[5] C. -M. Jang, D. -W. Kim, S. -Y. Lee, "Performance Characteristics of Turbo Blower in a Refuse Collecting System According to Operation Conditions", *Journal of Mechanical Science and Technology* 22, no. 10 (2008): pp. 1896-1901;
[6] Young-Bin Park, Choon-Man Jang, Sang-Ho Yang, "Pressure Characteristics According to the Duct Shapes of Turbo Blowers Connected in Serial", *Journal of Fluid Machinery* 13, no. 2 (2010): pp. 30-35;
[7] Jong-Sung Lee, Choon-Man Jang, "Performance Characteristics of the Double-Inlet Centrifugal Blower According to the Shape of an Impeller", *Journal of Fluid Machinery* 17, no. 1 (2014): pp. 28-34;
[8] Go Kawazu, Shingo Yamamoto, "New Type Turbo Blower Saves Energy", *JAPAN TAPPI JOURNAL* 71, no. 4 (2017): pp. 404-407;
[9] Atlas Copco, "Atlas Copco Launches New ZB 250 High-Speed Turbo Blower", *Atlas Copco*, https://www.atlascopco.com/en-ae/compressors/News-and-stories/launch-high-speed-turbo-blower;
[10] "Turbo Blowers and Compressors | Compressors | Howden", *Howden.Com*, https://www.howden.com/en-gb/products-and-services/compressors/turbo-blowers-and-compressors;
[11] Dutair, "Dutair Turbo Blowers Turn-Key Module for Highest Efficiency and Reliability", *Dutair.Com*, https://www.dutair.com/turbo-blowers;

[12] "COMOTI - Romanian Research and Development Institute for Gas Turbines", Comoti.Ro, http://www.comoti.ro/en/Suflante-centrifugale-de-aer.htm;
[13] Essi Paavilainen, "The performance and the characteristic field of a centrifugal compressor", Lappeenranta University of Technology, BH10A0200, Lappeenranta, 2008;
[14] Constantin VÎLCU, „Cercetări privind automatizarea maşinilor paletate de înaltă turaţie", INCD Turbomotoare - COMOTI, Program NUCLEU, Bucureşti, 2009