

OPTIMALIZACJA UKŁADU PRZEPŁYWOWEGO GAZU ZA POMOCĄ BADAŃ NUMERYCZNYCH I EKSPERYMENTALNYCH

OPTIMIZATION OF GAS FLOW STREAMS WITH THE USE OF NUMERICAL AND EXPERIMENTAL INVESTIGATIONS

Eugeniusz Rusiński, Przemysław Moczko, Piotr Odyjas, Maciej Zawisław – Faculty of Mechanical Engineering, Wrocław University of Technology
Zaklina Stamboliska – Cementarnica Usje AD Skopje

Częstym problemem w zakładach przemysłowych jest niewłaściwy przepływ energii cieplnej przenoszonej przez gazy procesowe wykorzystywane do suszenia materiałów. Rozwiązanie takiego problemu przez obliczenia teoretyczne potencjalnego rozkładu przepływu gazów jest często wystarczające, ponieważ rzeczywiste warunki eksploatacyjne mogą być złożone pod względem wahań ciśnienia, złożoności układu, zmian procesu itp. Artykuł opisuje bardziej dokładne podejście do problemu, na przykładzie problemu dotyczącego niewłaściwego rozkładu przepływów gazu w układzie mielenia i suszenia w cementowni. łączącego pomiar procesów na miejscu i dystrybucji przepływu modelowanie. Wykorzystane są badania eksperymentalne procesów przepływowych i modele oraz symulacje numeryczne odwzorowujące te procesy.

Frequent problem in industrial facilities is improper distribution of thermal energy carried by the process gasses for the purposes of drying. Solving this by simple theoretical calculations of potential gasses distribution is not sufficient as real exploitation conditions may be complex in terms of pressure variations, compound ductworks, process variations etc. The article describes reliable approach and a solution of improper gas flow distribution in grinding/drying facility in a cement plant combining process measurement on-site and modeling flow distribution.

Introduction

In many industrial branches process gasses are actually the main carrier of thermal energy required for drying and grinding raw materials. Plants are designed in a way to have certain distribution of the gasses in terms of quantity and velocities or pressure that is most favorable for the heat exchange with raw materials. It is also a fact, that plants are designed and build once, but with the time, conditions are changing in the facilities. Raw materials may change; the processing sequence or quality targets may change, upgrade of existing facilities may take place for various reasons etc. Saving energy lately top priority in today's plants thus requiring even more efficient utilization of energy of any kind. To answer these challenges, plants are required to make modifications of the equipment with smallest costs by properly planning these modifications to achieve best results. Investors ask for precise estimations of costs/benefits ratio and look for on-time achievement of results. This means that more and more combined approaches of measurements on site and computer simulation of possible outcomes are to be used for more accurate designing any process modifications.

In the paper a reliable approach is described that was used to design modification of raw materials drying and grinding line in a cement plant, that should have solve several problems at the same time. Major problems were related to poor flow of gasses bringing insufficient heat for drying materials in one section and a new demand for hot gasses to be used as inert gasses for drying coal thus creating additional lack of heat for drying/grinding. Combined numerical and experimental approach [1-2] of measurements on site to investigate real condition and computer CFD model, validated with the previous measurement results was used. The model enabled various

simulations of possible outcomes and finally best solution was designed and accepted. More detailed description of the problem, measurements and flow model is given in the article, as well as discussion of results achieved.

Problem description

Cement plant is typical example of heat energy recovery system by using the hot gasses from the main burning process (production of clinker) for drying and grinding raw materials and further their calcinations. In general, the process of clinker production consists of raw materials preparation; storage and homogenization; preheating and partial chemical transformation (precalcining); clinker burning and finally clinker cooling before storage. Raw material preparation means drying and crushing raw materials, mixing and grinding them in certain ratio to produce raw meal with required quality properties for the next stage of clinker production. To dry raw materials, in most cases hot gasses from the kiln are sufficient as they contain about 12,5 MW thermal energy. But, in some cases, additional hot gas generators have to be used to generate hot gasses and direct them to separate dryers, mills or separators if there is lack of heat coming from the kiln. In the cement plant under investigation, hot gasses from the kiln were used to dry raw materials in a drum dryer and additionally to separator and raw mill (gas distribution is shown on figure 1 with a solid line). Starting from the original design and installation, there were several upgrades and capacity increase made throughout the years that finally ended up with lack of hot gasses at the mill. Ducts positioning at the junction point of gas being distributed to separate sections of mill, dryer and bag filter is shown on figure 2 and it was very complex one. Additionally, the plant



Fig. 1. Flow-chart of gasses distribution (Legend: K4-Rotary kiln; VM-Vertical Mill; HGG-Hot Gas Generator; RM-Raw Mill; DD- Drum Dryer; BF-bag filter)

had to make one more modification and take part of the hot gasses from the kiln as inert gasses (about 45.000Nm³/h) to a new line for drying coal in so called Vertical Mill facility (VM). The new line is shown on figure 1 with dotted line

Contribution to these difficulties was also given by one existing horizontal section of large duct taking gasses to the separator that was constantly filled up with dust thus blocking the free entrance of the hot gasses to the mill (fig. 3). With such condition on site, the plant had to use Hot Gas Generator



Fig. 2. Real condition on site – gasses distribution

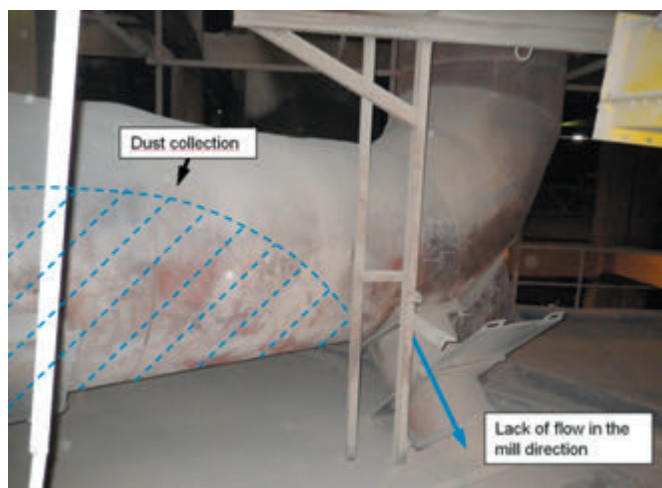


Fig. 3. Lack of hot gasses flow to the raw mill

(HGG) to dry the main raw material thus consuming additional 8kcal/kg raw mill or about 7.000MWh energy consumed per year for average clinker production of 500.000tpa. Even with HGG, still there were serious difficulties with the flow of the hot gasses in the ducts and almost no gasses were flowing through the mill. This has resulted in insufficient raw meal drying while grinding. The required target of less than 1% moisture couldn't be achieved and higher moisture in raw meal asked for more energy for clinker burning, thus increasing the overall energy consumption for about 1-2kcal/kg clinker or 600 to 900MWh in a year for the investigated plant.

The other problem that was also mentioned previously was that with the new connection for inert gasses the control of the raw material preparation line was impaired as the new line was connected at the mill section. In case of need for inert gasses, the raw mill section had to be open and if there would be malfunctioning of mill, the inert gasses couldn't be provided. Also, having need for inert gasses, there couldn't be proper regulation of the gasses towards the drum dryer that was doing the main drying of the main raw material. Even more, the existing HGG was connected only to the raw mill side, so no additional heat could be transferred to the drum dryer in case major part of the hot gasses from the kiln would be taken as inert gasses to the new facility. Considering all above, the following major issues were drawn to be solved:

- Providing solution to compensate up to 45 000 N m³/h of hot gasses taken for coal drying (VM line) with the use of hot gas generator.
- Providing solution to prevent dust collection in the horizontal duct in the mill line (see fig. 2.3).
- Providing solution assuring gas flow through mill line for proper drying/grinding of raw meal (see fig. 2.3).

Investigation and discussion of results

Considering that it was complex problem that needed to be solved by combing the existing installation with new smallest possible modifications and still be able to predict results with sufficient accuracy, decision was made to use combination of measurements on site and make computer flow model of the current situation, validate it by the measurements on site and then by simulating various possible solutions, find the most optimal one. The most optimal solution besides solving the three mentioned problems, should have also provided making the modification in a way that no new complexities would come up, to be easy to perform modifications with smallest costs and provide long-term quality solution (low abrasion, less direct exposure to hot gasses from the HGG).

On-site measurements

The main goal of flow measurements was to establish current flow conditions and behaviour of the system in few different modes of operation. Based on these measurements current gas flow distribution, flow rates and pressures could be evaluated thus providing estimation of the system flow behaviour and redesigning solutions required in the future operation (intake of inert gasses for coal grinding facility- VM line).

Measurements of the raw material preparation line was made in four different modes of operation: **Mode 1:** compound mode (gasses trough mill and dryer); **Mode 2:** approximately direct

mode (main gasses directly to the filter, no gasses through the mill and some gasses through the dryer); **Mode 3:** semi-direct mode 1 (all gasses through the dryer) and **Mode 4:** semi-direct mode 2 (all gasses through the mill and to the filter). Locations of measurement points were chosen to enable measurements of flow parameters in each part of raw material preparation line (mill; mill-separator; dryer-cyclones; filter). Overall 8 measurement points for full flow measurements were selected as shown in figure 4. Following parameters were recorded in all measuring points:

- 1) Dynamic pressure measured with S Pitot tube and differential pressure transmitter.
- 2) Static pressure measured with use of gauge pressure transmitter.
- 3) Barometric pressure measured with use of barometer.
- 4) Ambient temperature measured with use of electronic thermometer.
- 5) Gas temperature measured with use of thermocouple.

Measurements were made in accordance with following standards: PN-G-04161:2003, PN-Z-04030-7:1994, PN-M-42367:1981, PN-M-42366:1981, and ISO 10780 and ISO 3966. Measured signal was processed in LMS Scadas Recorder. Chemical composition of gasses was ~21% of CO_2 , ~3% of O_2 , ~76% of N_2 and water content ~1% and density of $1,42\text{kg/m}^3$. On figures 3.1 to 3.3 measuring results are shown in various modes of operation.

A basic result of measurements as amount of gasses and temperatures of operation are presented on the basic flow-charts in figures 4 and 5 for modes no. 1 and 2.

Discussion of results

Flow balance of the entire system is shown in table 1. More detailed flow-balance analysis was made for each section of the

investigated line like raw mill (inlet-outlet), mill and separator (inlet-outlet), drum dryer and cyclones (inlet-outlet), bag filter (inlet-outlet).

Related to standard conditions, results showed that in each mode gas amount in the system increases. This means that during gas flow through the ducts, an additional false air enters the system. In case of mode no. 2, the flow increase is almost equal to zero. During this mode of operation increased dust emission was observed. The values of static pressures are much smaller than in other Modes. In addition the positive pressure has been measured in point no. 7 before drum dryer. What is more, drum dryer and cyclone flow balance shows decrease in gas flow in comparison to other Modes of operation. In this case (especially in drum dryer line) some gas volume goes out from system, which was also confirmed by results obtained in operating conditions which show decrease of the gas flow rate. Pressure and velocity changes in the measured line are shown in table 2.

Flow model

Numerical model of the raw preparation system was created. The model was validated according to flow measurements results, presented in section 3.1. Numerical calculations were performed with the use of finite element method in the ANSYS FLUENT CFD software based on the three dimensional model of the raw preparation system [3-4]. The model is presented on fig. 6. Based on the results of measurements, the flow through the raw preparation line was calculated for the modes of operation considered during flow measurements. Visualisation of velocities of gas flow for examples of mode no. 1 is shown on figure 7.

Obtained numerical results were compared and adjusted to be in line with the measurement results. This way the model

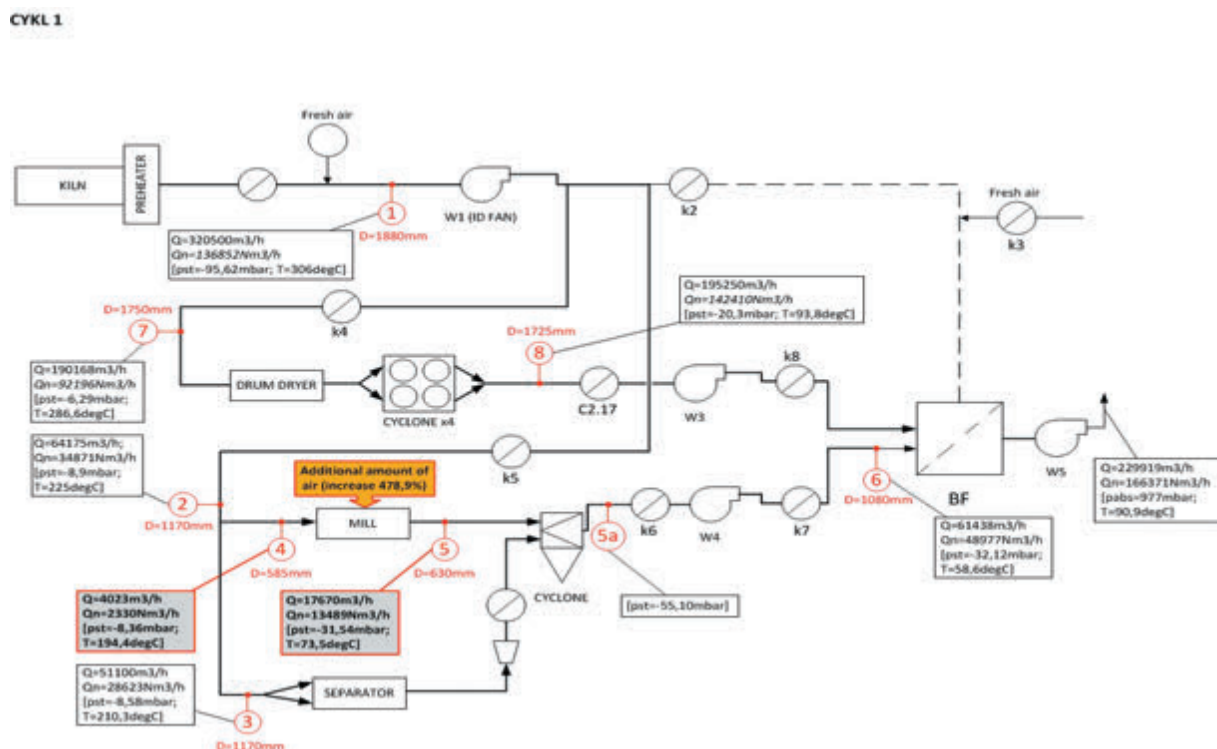


Fig. 4. Measuring results in mode 1

CYKL 2 (Kłapy nr C2.17 otwarte tylko w 42% tak, aby wymusić zwiększony przepływ przez młyn (mill))

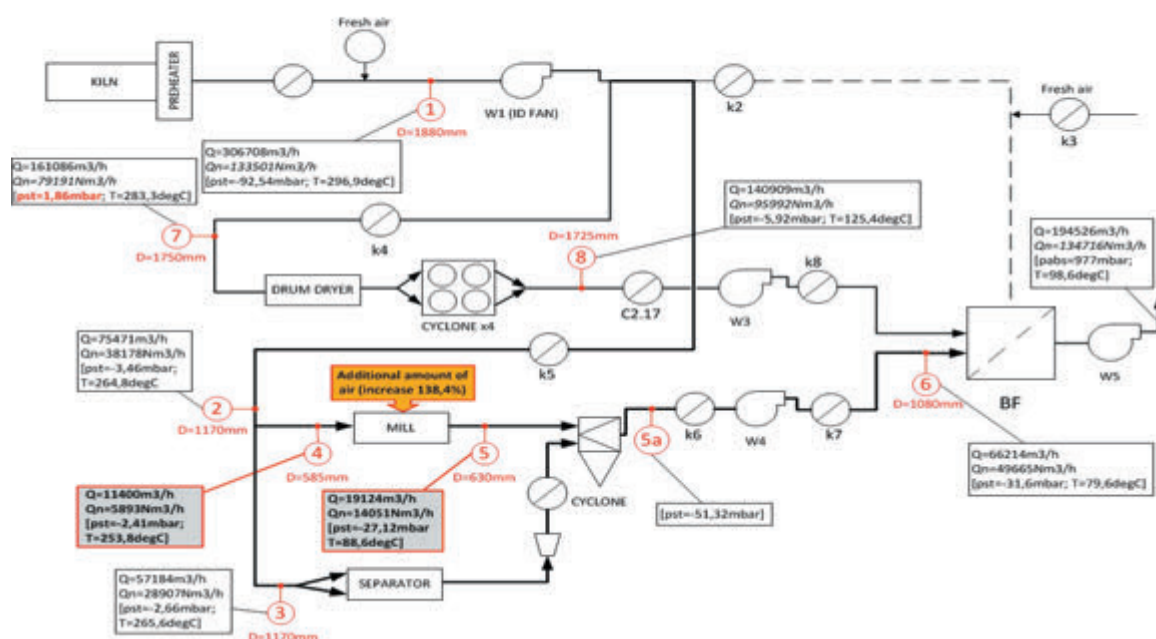


Fig. 5. Measuring results in mode 2

was set to be used for future testing of modification solutions to assure proper operation of the system with new VM line connected and check the improvement of gasses flow to the mill.

To enable proper operation of the system with consideration of installation of new hot gas generator or use the old one for

Tab. 1. Comparison of the inlet and outlet flow in different modes

Mode of operation	Date	Inlet flow (point no. 1)	Outflow (after filter)	Flow rate increase	
				[Nm ³ /h]	%
1	18.04.2013	130.079	178.308	48.229	37,1
	19.04.2013	136.852	166.371	29.519	21,6
2	20.04.2013	133.501	134.716	1.215	0,9
3	22.04.2013	102.569	172.502	69.933	68,2
4	23.04.2013	130.274	171.792	41.518	31,9

Tab. 2 Pressure and velocity changes

Measurement point	pst [mbar]				v [m/s]			
	Mode 1	Mode 2	Mode 3	Mode 4	Mode 1	Mode 2	Mode 3	Mode 4
p1	-95,62	-92,54	-107,81	-95,3	32,07	30,69	24,41	30,04
p2	-8,9	-3,46	-13,38	-3,4	16,58	19,5	13,64	~2,00
p3	-8,58	-2,66	-13,21		13,21	14,77	10,88	
p4	-8,36	-2,41	-12,94		4,16	11,78	2,34	
p5	-31,54	-27,12	-32,65	-3,6	15,75	17,04	14,83	
p5a	-55,1	-51,32	-56,11					
p6	-32,12	-31,6	-30,02		18,63	20,08	17,35	
p7	-6,29	1,86	-12,35	-8,98	21,96	18,6	20,19	28,75
p8	-20,3	-5,92	-25,68	-28,82	23,21	16,75	22,62	29,31

compensation of new designed gas outflow for coal grinding installation (VM), advanced flow simulations were performed.

Following the targeted of this investigation, analysis of amount of gasses having in the existing situation in separate lines (section) was determined (92.000 Nm³/h to the drum dryer and 31.000 Nm³/h to the mill and separator). Than the new line to VM was added with the amount of gasses to be taken (45.000 Nm³/h) and residual gasses amount trough the existing lines of mill and dryer was estimated (14.000 Nm³/h to the drum dryer and 0 Nm³/h to the mill and separator). The both situations are shown in figure 8 (existing situation with blue line and new with red lines).

Considering present amount of gas going through the raw preparation line, it is clear that entire present amount of gas in the mill line will be taken to VM line. Therefore the total amount of 31 000 Nm³/h in this line must be compensated by HGG. The remaining 14 000 Nm³/h will be provided to the drum dryer line (fig. 8).

The redesign solution should have assured such compensation in both mill and drum dryer lines to enable proper operation



Fig. 6. Geometrical 3D model of the RAW PREPARATION line considered in the calculations

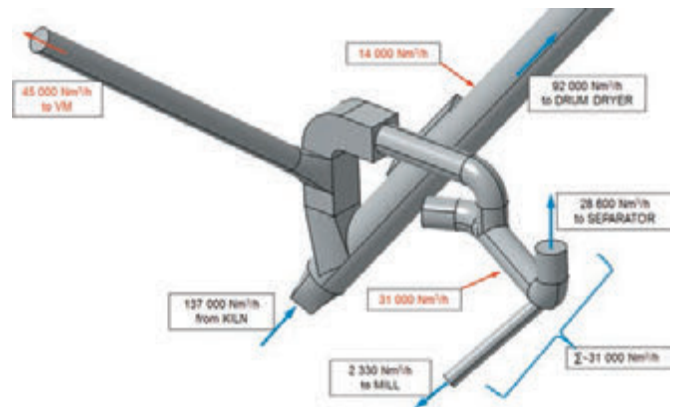


Fig. 8. Normal operation flow through the raw preparation line and amount of gas to the new VM line

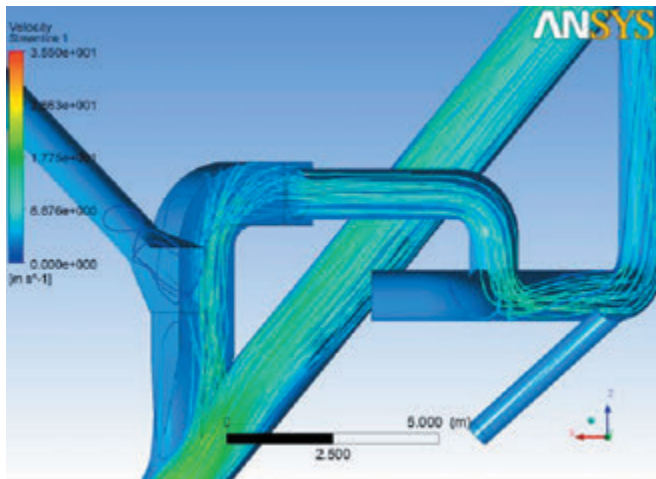
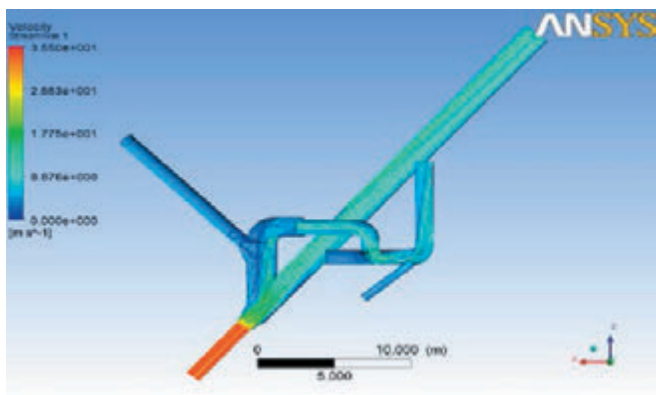


Fig. 7. Flow velocities of the measured line – mode 1, existing system

when VM is in operation. Based on the results of measurements, two redesign solutions were proposed:

- Solution no. 1 – the existing connection of the mill line is cut and reconnected to drum dryer line right after new connection of the hot gas generator. The solution is shown in figure 9.
- Solution no. 2 – the existing connection of the mill line is cut and reconnected to drum dryer line. The new hot gas generator is connected to existing line of old HGG, which is relinked to drum dryer line. The solution is shown in figure 10.

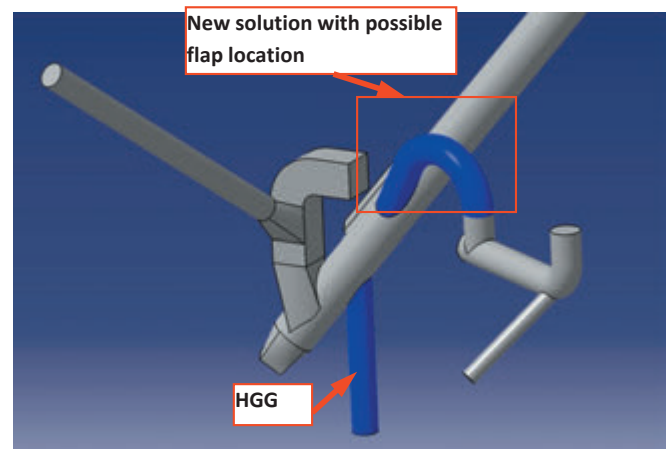


Fig. 9. Redesign solution no. 1

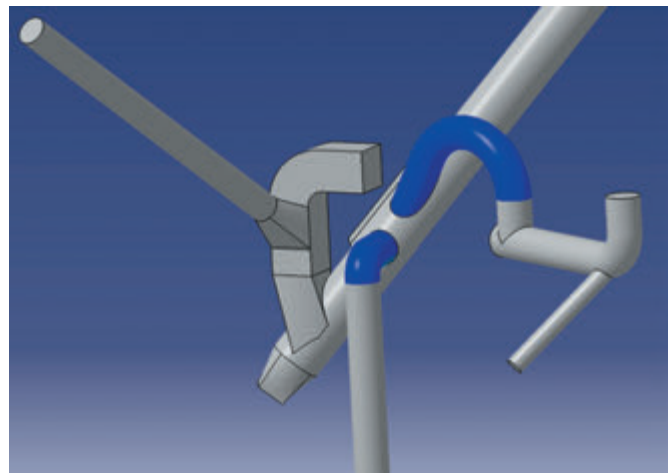


Fig. 10. Redesign solution no. 2

Based on the preliminary calculations it was found that redesign solution no. 2 is significantly worse than solution no. 1. It is caused by direction of HGG duct, which is perpendicular to the drum dryer duct. It is also inconvenient that gas from HGG enters the drum dryer duct and is directed then to direct mode duct. Considering above the redesign solution no. 1 was chosen as more optimal to further flow analyses.

Tab. 3. Comparison of flow for existing and modified raw preparation line for different modes of operation

Cross section (fig. 4)	Mode 1 [kg/s]	Mode 1 -45 [kg/s]	Mode 1 mod [kg/s]	Mode 1 mod -45 [kg/s]	Mode 1 mod -45 +45 [kg/s]
Inlet (inlet to raw preparation-kiln hot gasses)	48	48	48	48	48
outlet_1(to the drum dryer)	-35,97	-27,28	-34,96	-22,14	-35,7
outlet_2 (to the separator)	-9,76	-3,24	-10,24	-6,43	-10,14
outlet_3 (to the mill)	-2,19	0,26	-2,76	-1,49	-2,2
outlet_4 (to VM)	0	-17,7	0	-17,96	-17,91
inlet_5 (inlet to raw preparation from HGG)			0	0	18

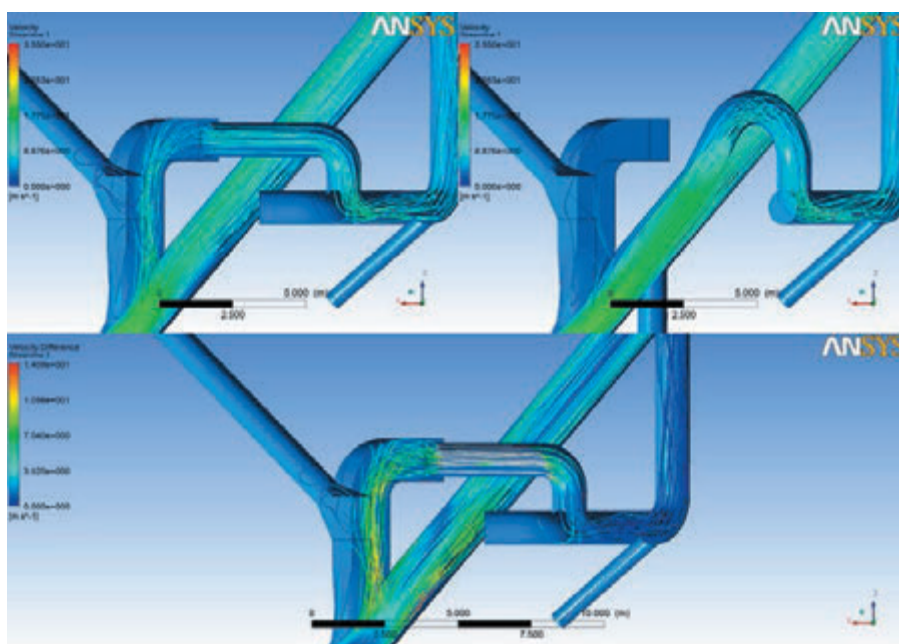


Fig. 11. Flow comparison – existing and redesigned solution – Mode 1, normal operation

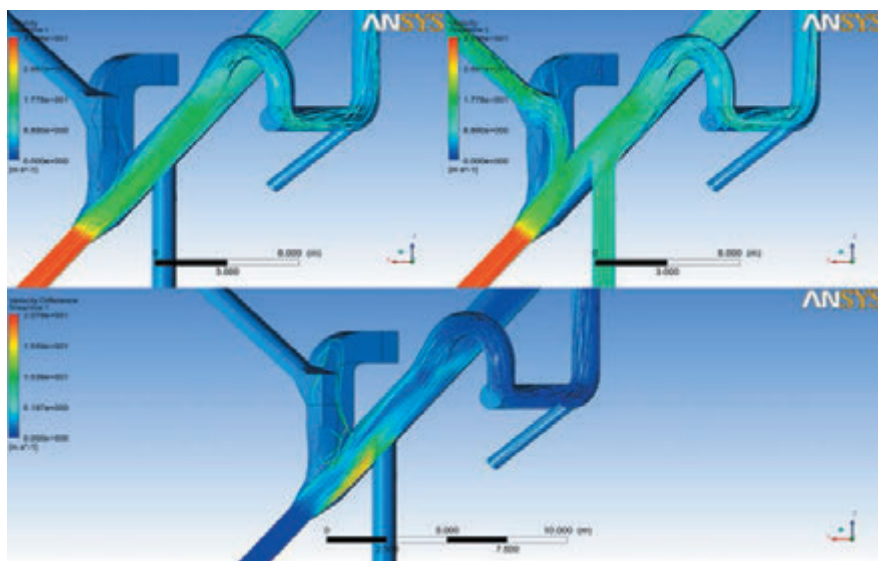


Fig. 12. Flow comparison – redesign solution: Mode 1, normal operation; redesigned solution: Mode 1, normal operation 45 000 Nm³/h to VM, 45 000 Nm³/h from HGG

Flow calculations and discussion of results

Flow calculations were performed for the two models of the raw preparation line, the existing line and redesigned line (solution no. 1). In the calculations the regular operating modes are considered and in addition the new condition with required gas amount ($45\,000\text{ Nm}^3/\text{h}$) taken to the VM and than compensated by HGG. Results of calculations are presented in table 3, where comparison of flow amount for existing and redesigned (modified) raw preparation line is shown for different modes of operation, considered at same locations as measurements taken on site.

Results of flow calculations are also shown in figures 11 to 12 where comparisons between existing and redesigned solutions for different modes of operations are presented.

Based on the results of flow calculations on the existing and redesigned raw preparation line for different modes of operation following could be concluded:

1. Redesigned line (solution no. 1) operates properly for all modes considered in the tests and calculations.
2. Redesigned solution no. 1 improves slightly flow through the mill line.
3. The existing flap, which controls flow through the mill line cannot be used in modified solution anymore. This flap can be relocated to the newly designed junction between drum dryer and mill line or new flap shall be located there.
4. It is required to perform adjustments on the flaps controlling the flow through drum dryer and mill lines to obtain required flow parameters.

Conclusions

Integration of numerical simulations and experimental tests enables solving complex technical and scientific problems [10-12]. Such approach provides reliable solutions in acceptable time with low risk of implementation [5-6, 9]. It is more and more popular to improve efficiency of machines and processes in order to obtain better products and lower production costs [7, 8]. With the presented experimental and numerical

approach, this can be achieved. In this paper example of such work is presented. The main aim of the investigation was to redesign of the existing raw material preparation line to enable its normal operation with consideration of the new line for coal grinding facility and solve problems with gasses flow to the mill. Considering the complex ducts works in the facility and many modifications performed, as well restriction by the present building, it was decided to apply combined approach:

- Investigate the existing condition and mapping current difficulties by doing measurements of gasses flow in the lines of raw material preparation.
- Create model of the system, validate the model with consideration of measurements results.
- Redesign of the raw preparation ductworks line in order to prevent existing problems with the gas flow and with consideration of installation of new or re-use existing hot gas generator for compensation of new designed gas outflow for coal grinding installation.

The core issue was to create proper model and validate it with measurements results made on the existing line. Such complete virtual model enabled simulation of the planned changes for the plant (new gasses outflow for drying coal, new flow of gasses from the HGG) and at the same time estimated what would happen with existing lines in the raw preparation line (dryer and mill-separator) as the plant has to continue operating. Numerical calculations were performed with the use of ANSYS FLUENT CFD software. The three dimension modelling was considered as the best approach for such a complex object.

Based on results of flow measurements and numerical simulations of the chosen solution, it can be concluded:

1. The redesigned solution will enable proper operation of the raw preparation line with new coal grinding facility and hot gas generator connected.
2. No problems with the gas flow in the mill line will be present due to relocation of connection of dedusting system previously connected to the raw mill line.
3. The solution requires smallest investment costs due as there is only small new duct to be constructed and relocation of existing flap.

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