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Energy Saving Technology for Lowering Air Leakage of Sintering Pallets and Dust Collectors in Sinter Plant

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Abstract: The hot-wire type anemometers were used for measuring the velocity of effective air flowing through sinter bed in this study. Meanwhile, microphones were installed beside the pathway and close to the outer sidewall of travelling pallets for monitoring sound pressure generated by an abnormal air leakage. For identifying the passing pallet, a thermal-resistant type RFID technology was adopted. Based on the measured data via anemometers, the air leakage rate of sintering machine was calculated with the mass balance method, and pallets with the abnormal leakage can be detected and ranked in the severity of leakage from the measured sound pressure with the relevant criteria. In addition, for examining the leakage situation, this study set up a capillary type of differential pressure gauge to double cone valve (DCV) below the electrostatic precipitator (EP) in sintering plant for collecting the larger dust. The criteria of determining leaked DCV and the patterns for replacing the DCV were proposed to develop a detecting and predicting system on the air leakage into dust collectors of sinter machine. It offered field staff a basis of maintaining or renewing DCV via a warning reminding and reducing air leakage to increase EP efficiency for avoiding the dust emission from the stack. These technologies had been implemented in the sintering plants of China Steel Corporation, and they can effectively reduce the air leakage rate by 5% at least and further decrease the electricity consumption of the suction fan and coke rate, increase the production for the sintering machine.

Key words: Sintering machine, air leakage rate, pallets, double cone valve, on-line detection.

1. Introduction

Iron ore sintering process is an agglomeration process to convert iron ore fines into lumpy agglomerates, which is charged into blast furnace as a major iron material. Iron ore fines, fluxes and coke breeze are mixed with water to form granules, which is laid onto a moving sinter strand through a surge hopper, roll feeder and segregation device as a pack bed. The sinter strand moves along a series of windboxes, which are connected to a suction fan. The bed is first ignited from the top while airflow is sucked through the bed into the windboxes. In this way, coke breeze is combusted and the flame front progressively moves down the bed, and the fine particles of iron ores and fluxes are heated by burning coke breeze and melted. The sintering machine structure is made up of many sintering pallets with sealing devices located in front and behind each one. These devices come into contact with a hard metal plate at the bottom of the pallet beam and the side of the bellows. To prevent rubbing against the sharp sintering charge during the sintering process, which results in scratching and air leakage, expansion space is required. If the sintering machine pallet has a leak, ventilation decreases, which causes difficulties in forming the pellets and decreases sinter output. An intact sintering pallet uses less electricity and has a lower system fan load because it does not have any leaks. A pallet with a leak requires the fan to rotate at a higher speed to maintain a certain amount of ventilation, so the motor driving the fan provides a higher drive current and wastes more energy [1].

Air leakage of sintering machine means that there is no effective air flow through the sinter bed for going in the agglomeration reaction, and it mainly passes

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through the leakage points into the main exhaust sintering pipe to cause the decrease of effective flow volume through sintering bed based on the fan suction force, shown as Fig. 1. The air leakage in sintering process of iron ore is one of the problems which cannot be solved completely, thus, accurately measuring the air leakage rate of sintering machine can effectively monitor the changes of the air leakage, and it enabled the maintenance staffs to take effective ways to repair and appropriately replace the air-leakage equipment. Currently, the air leakage rate for world-class sinter plant was about 30-35% [2]. In general, more than 50% of the air-leakage occurs at the pallets themselves and the interfaces between the pallets and the wind boxes, and it was well known for the importance of air-leakage detecting in sintering pallets. In the past, man power was used to perform air leakage tests during the sintering machine operations. Under conditions where a lot of dust and noise (approximately 90 to 110 dB) were present for extended periods of time, staffs had to make judgments based on what they could see and hear. However, tracing the source of a leak can be very difficult because leaks can occur at different points such as the charge level or the pallet. In addition, the degree of noise made by the leak is not necessarily related to the amount of air leaked. It is difficult to judge if a leak is serious by simply listening to the leak. Moreover, manual test results are difficult to quantify and record and cannot be used as a reliable reference for sintering pallet overhaul. At present, the flue gas analysis and oxygen content analysis technologies were the main methods for determining the air leakage rate of sintering machine. However, there were some problems needed to overcoming, such as existence of a larger simultaneous workload of gas sampling and a complicated operation process, the need of a long-term continuous detection, and inability to identify specific air leakage locations [3].

To increase the productivity of our sintering plant, an effective way was needed to test for the air leakage sources and analyze the leakage data as the basis for regular overhaul and replacement of the sintering pallets. An automated air leakage detecting system was developed that allows staffs to conduct immediate testing and monitoring of the air leakage status of all sintering pallets by operating the system which was used to carry out signal analysis and data recording as the basis for future sintering pallet overhauls.

A significant amount of waste gas including dust, sulfur oxides (SO_x) and nitrogen oxides (NO_x) is released to the air with a negative impact on the air environment. Electrostatic precipitators (EP), De-SO_x and De-NO_x systems have been installed to reduce exhaust emissions from sintering plants [4]. Double cone valve (DCV) is a kind of dust discharging valve of EP, the major function is for collecting the larger dust inside EP in sintering plant. DCV leakage will reduce EP efficiency thus cause the dust emission from the stack. Therefore, it is quite important to replace the DCV appropriately for avoiding leakage owing to a long-term mechanical abrasion. In the past, the field staffs determine this leakage by means of listening. However, it is time-consuming, laborious and not effective necessarily. This study aimed to set up a gauge and a method for examining the DCV leakage as indicator to timely replace the DCV [5]. Now, the improvement of the air leakage for DCVs all over the world tried to focus on the amelioration of the mechanical or electrical system parts, and optimize the sealing ability and mechanical stability. However, the cost is significantly increased when the equipment improvement is fully implemented, in addition, the two metal cones inside the DCV equipment were repeatedly impacted with each other, and it caused the inevitable occurrence of metal surface wear. Therefore, the test of improving double cone valve was actually challenging many studies of DCV sealing, and there is no detection system for the air leakage of double cone valve currently.

This study thought that providing an effective and automatic predicting system for the on-site maintenance

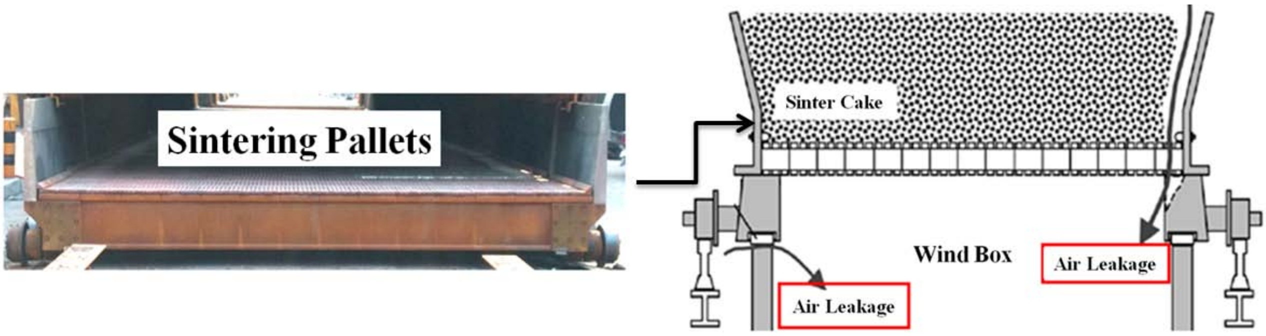


Fig. 1 Schematic diagram of air leakage occurred in a sintering pallet.

or the operation staffs based on the consideration of reducing the air leakage from the sintering pallets and DCVs, and that increasing energy saving leakage should be more feasible options.

2. Research Method

2.1 Measurement System on Air Leakage Rate of Sintering Machine

2.1.1 Measurement Method

In this study, six hot-wire anemometers with corresponding protective sleeves which aligned the lateral orientation of the six sets of sub-gates at the bottom of burden hopper were fixed on the movable support across the sinter bed and used to measure the effective suction wind velocity into the sinter surface. Then moving (scanning) the stand to measure the wind velocity into the sinter surface in the entire sintering regions, the measurement system was shown in Fig. 2.

2.1.2 Principle of Mass Balance

The total amount of air (V_{total}) drawn into the flue from suction fan consists of three parts, one is the effective amount of air entering the sinter layer (V_{in}), the second is the amount of harmful air leakage in the sintering system ($V_{leakage}$), the third, the amount of additional gas ($V_{additional}$) in the physical variations or chemical reactions of the material layer in the sintering process. However, mainly the amount of additional gas was the volume of moisture in the mixture changed to the volume of water vapor, that is, $V_{additional} = V_{H_2O}$(gas). Considering the actual sintering reactions courses in this study, it was believed that the water content between particles and particles in the mixture can be completely evaporated into water vapor at 100 °C, but the actual reaction temperature in sinter layers was far high than 100 °C, therefore, the crystal water ratio in the particles in the mixture should be also completely evaporated, so this study added an additional ratio of crystal water to estimate the complete amount of water vapor. The volume of water vapor at the standard state was shown as Eq. (1):

$$V_{H_2O,s} = (100 - k) \times 22.4 \times n_{H_2O} = \frac{22.4(100-k)\lambda(\alpha+\beta)WHv}{18} \tag{1}$$

where: n_{H2O}, the amount of water in the mixture per unit time, mol.

λ, the bulk density of the mixture, kg/m^3.

α, the water ratio between particles and particles in the mixture, %.

β, the ratio of crystal water in the particles in the mixture, %.

W, pallets width, m.

H, height of sinter bed, m.

v, the moving speed of pallet, m/s.

k, the assumption ratio of wet material in the entire sinter bed volume during the measurement, %.

2.1.3 Sintering System Air Leakage Ratio (SL)

For the effective wind entering the surface of sintering bed was different in the state of the wind in the flue, the calculation of the air leakage rate must be converted to the same standard state, as shown in Eq. (2).

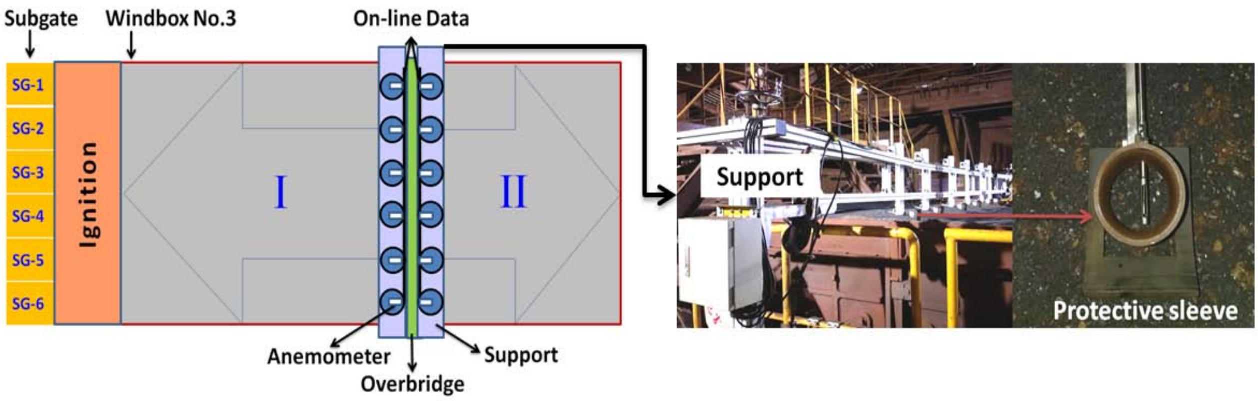


Fig. 2 **Schematic diagram of a measuring method with the effective flow into sinter surface.**

$$SL = \frac{V_{total,s} - V_{in,s} - V_{H2O,s}}{V_{total,s} - V_{H2O,s}} \times 100\% \qquad (2)$$

2.2 Ranking System for the Air Leakage in the Sintering Pallets

2.2.1 Air Leakage Detection System for Sintering Pallets

A microphone array measurement was installed beside the pathway and close to the outer sidewall of the travelling pallets for monitoring the sound pressure generated by the abnormal air leakage, and the thermal-resistant type RFID technology was adopted for the identification of each pallet in this study.

2.2.2 Air Leakage Alarm Criteria for Sintering Pallets

Set a threshold value of the sound pressure as the baseline for judging the air leakage alarm, and record the alarms number of each pallet while an average value of the sound pressure calculated from each microphone was greater than the threshold, then list the ranking of the sound pressure (air leakage) from the sintering pallets.

2.2.3 Verification Work after Renewing the Pallets

Replace the top few pallets in a ranking list with the newly numbered pallets sequentially in a short-term downtime, and further observe the newest ranking after the replacement of pallets, then examine the damaged positions of each removed pallet.

2.3 Detecting System for Air Leakage of Dust Collectors

2.3.1 Experimental Procedures

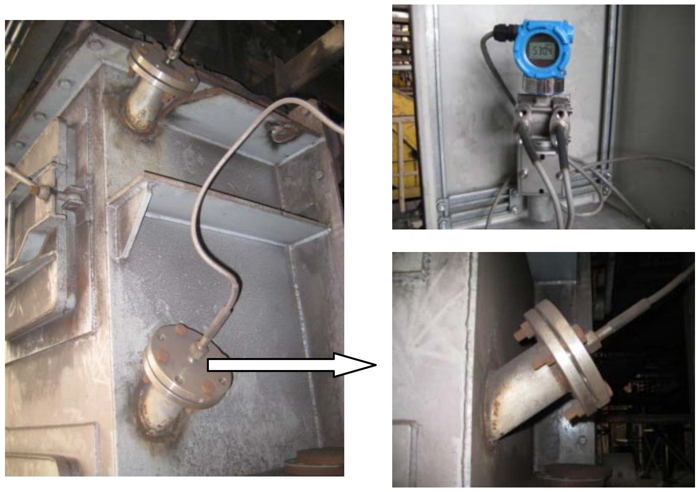
A capillary type of differential pressure gauge was installed on the DCV below the EPs of sinter plants. It was examined by identifying the pressure pattern to detect air leakage inside discharging valve and the stability of the device during the periodic operation of DCV. The sensor of differential pressure gauge was mounted directly external to the pressure source to measure pressure variation (input), then the digital signals (output) was transmitted to microcomputer by the capillary. The main advantage was that no dust clogged the pipe conveying the pressure signal to general pressure transmitter. However, if a large amount of dusts or pollutants appeared in the pressure source, the sensor may be polluted and worsen the measurement accuracy. Therefore, the franges (embedded sensors) were used to connect to DCV in 45-degree angle down for reducing dust pollution, as shown in Fig. 3.

2.3.2 Theoretical Analysis

The geared motor drives the roller rotation periodically, and the roller drives the mechanical arm connecting the above and below discharging valve of DCV, which discharges the dust particles caught from EP in the operation cycle as following:

(i) Top and bottom cone both remains closed and materials are collected over top cone.

(a) Capillary type of differential pressure gauge



(b) DCV (c) Installing differential pressure gauge on the DCV

Fig. 3 Installing of differential pressure gauge on the DCV below the EPs of SPs in CSC.

(ii) Top cam opens and closes with bottom cam remaining closed. As soon as the geared motor starts, the roller will push the top cam lever to rotate along with the spindle thus opens the top cone and allows the materials to fall and be collected over bottom cone. As soon as the roller leaves the cam lever, the top valve closes completely.

(iii) Top and bottom cones remain closed during the intermediate span of roller travel before it touches the bottom cam lever.

(iv) Bottom cam opens while top cone remains closed, and discharges the collected materials. The smooth closure of the bottom valve cone will be similar to that of the top cone.

The schematic diagram is shown as Fig. 4. From the diagram, the theoretical pressure pattern inside DCV can be predicted as Table 1 and Fig. 5.

2.4 Flow Chart of Energy Saving Technology for Lowering Air Leakage of Sintering Machine

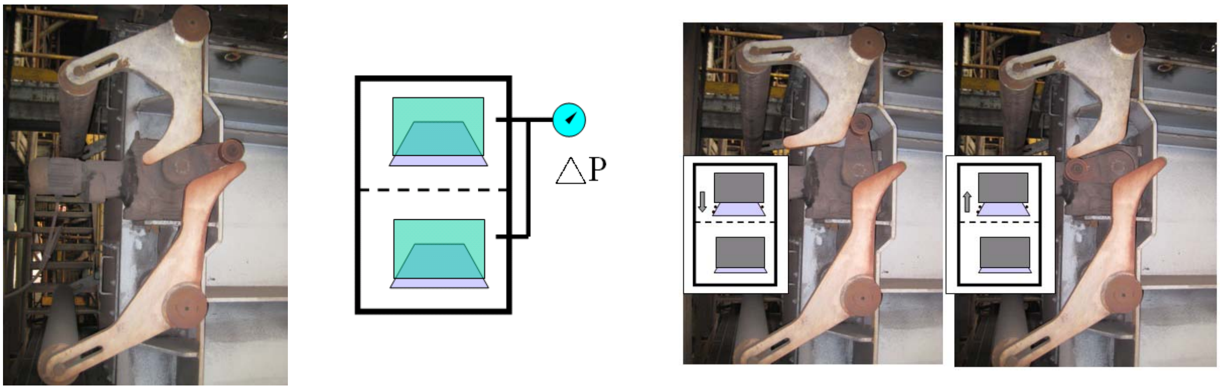
The entire research flow chart was shown in Fig. 6.

3. Results and Discussion

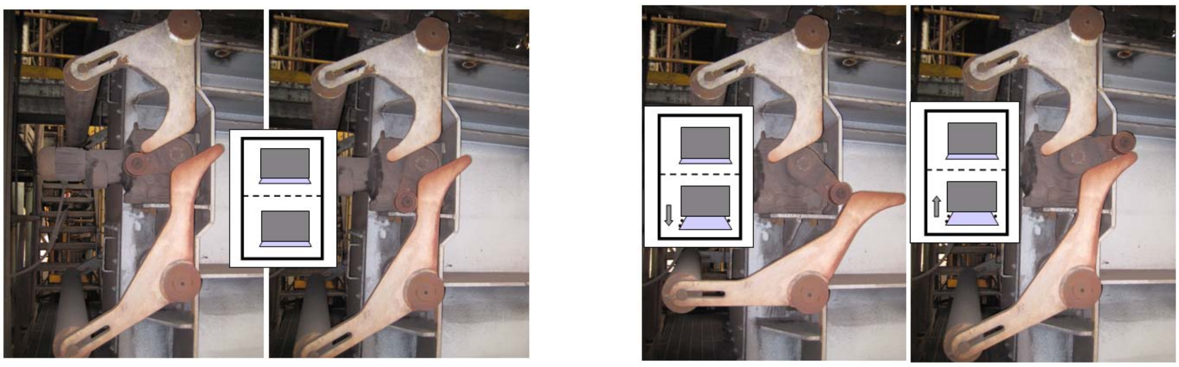
3.1 Air Leakage of Sintering Pallets

3.1.1 Development of a Measurement System for the Air Leakage Rate of Sintering Machine

During the measurement course, the data of wind velocity from the regularly moved six anemometers could be continuously collected on the horizontal surface of sintering bed from the leaving ignition to the end of sintering in a short-term period, and local wind velocity of all positions scanned by six anemometers in travelling direction of pallets and the entire average effective wind velocity into the sinter



(a) Top cone close, bottom cone close (b) Top cone open, bottom cone close



(c) Top cone close, bottom cone close (d) Top cone close, bottom cone open

Fig. 4 Diagrams of DCV operation cycle.

Table 1 Theoretical pressure variation inside DCV in operation cycle.

DCV leakage	Pressure variation	Top cone close Bottom cone close	Top cone open Bottom cone close	Top cone close Bottom cone close	Top cone close Bottom cone open
Top cone normal Bottom cone normal	Top cone	Pa	P_{EP}+Pa	P_{EP}+Pa	Pa
	Bottom cone	Pa	Pa	Pa	Pa
	ΔP	0	P_{EP}	P_{EP}	0
Top cone normal Bottom cone leakage	Top cone	Pa	(Pa +αP_{EP}, 0<α<1) to (Pa +P_{EP})	(P_{EP}+Pa) to Pa	Pa
	Bottom cone	Pa	Pa	Pa	Pa
	ΔP	0	αP_{EP} to P_{EP}	P_{EP} to 0	0
Top cone leakage Bottom cone normal	Top cone	Pa to Pa+P_{EP}	P_{EP}+Pa	(P_{EP}+Pa) to (Pa +βP_{EP}, 0<β<1)	Pa
	Bottom cone	Pa	Pa	Pa	Pa
	ΔP	0 to P_{EP}	P_{EP}	P_{EP} to βP_{EP}	0
Top cone leakage Bottom cone leakage	Top cone	Pa to (Pa+αP_{EP})	(αP_{EP}+Pa) to (P_{EP}+Pa)	(P_{EP}+Pa) to Pa	Pa
	Bottom cone	Pa	Pa	Pa	Pa
	ΔP	0 to αP_{EP}	αP_{EP} to P_{EP}	P_{EP} to 0	0

※ Pa: Atmospheric pressure, P_{EP}: Negative pressure of EP, α: Leakage parameter of bottom cone, β: Leakage parameter of top cone.

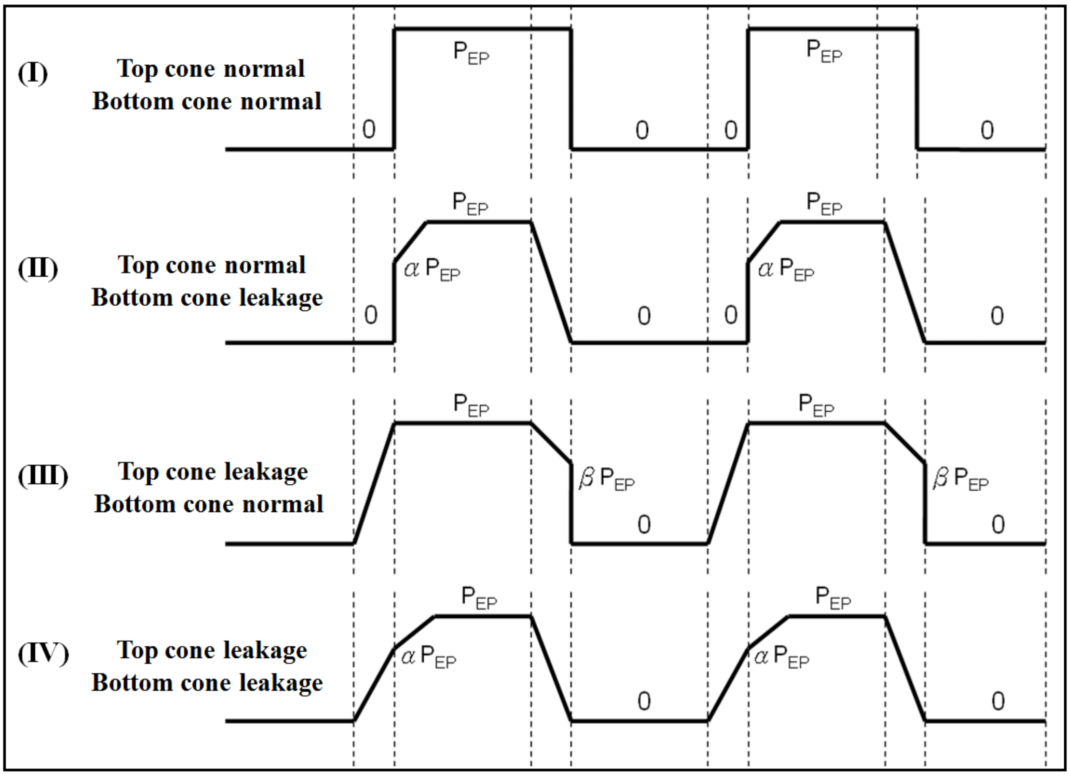


Fig. 5 **Diagram of theoretical pressure pattern inside DCV (Y direction) versus operation cycle (X direction).**

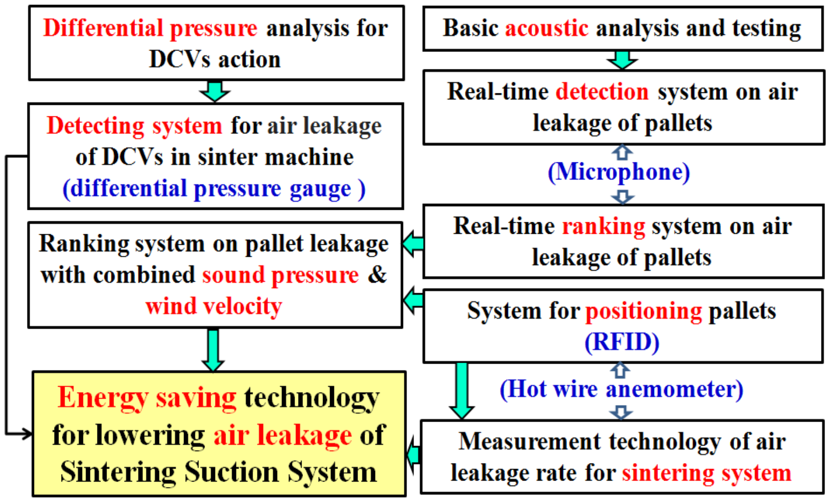


Fig. 6 **Research flow chart in this study.**

surface could be measured quickly, then, the average effective air volume through sinter bed was also calculated based on multiplying by the area of the sinter bed. Finally, the instantaneous air leakage rate of the sintering system was obtained via the mass balance correction of air flow. A calculated instance with the air leakage rate of the sintering machine in this study was shown in Fig. 7.

It showed the average effective air volume through the sinter bed was 451,650 m^3/hr calculated from a real-time measurement of the anemometers which showed an average effective wind velocity on the sinter surface (0.398 m/s). During the measuring period, the average temperature, wind velocity and cross-sectional area of flue gas in the stack were 142.5 °C, 12.23 m/s, and 25.44 m^2, respectively, and total air

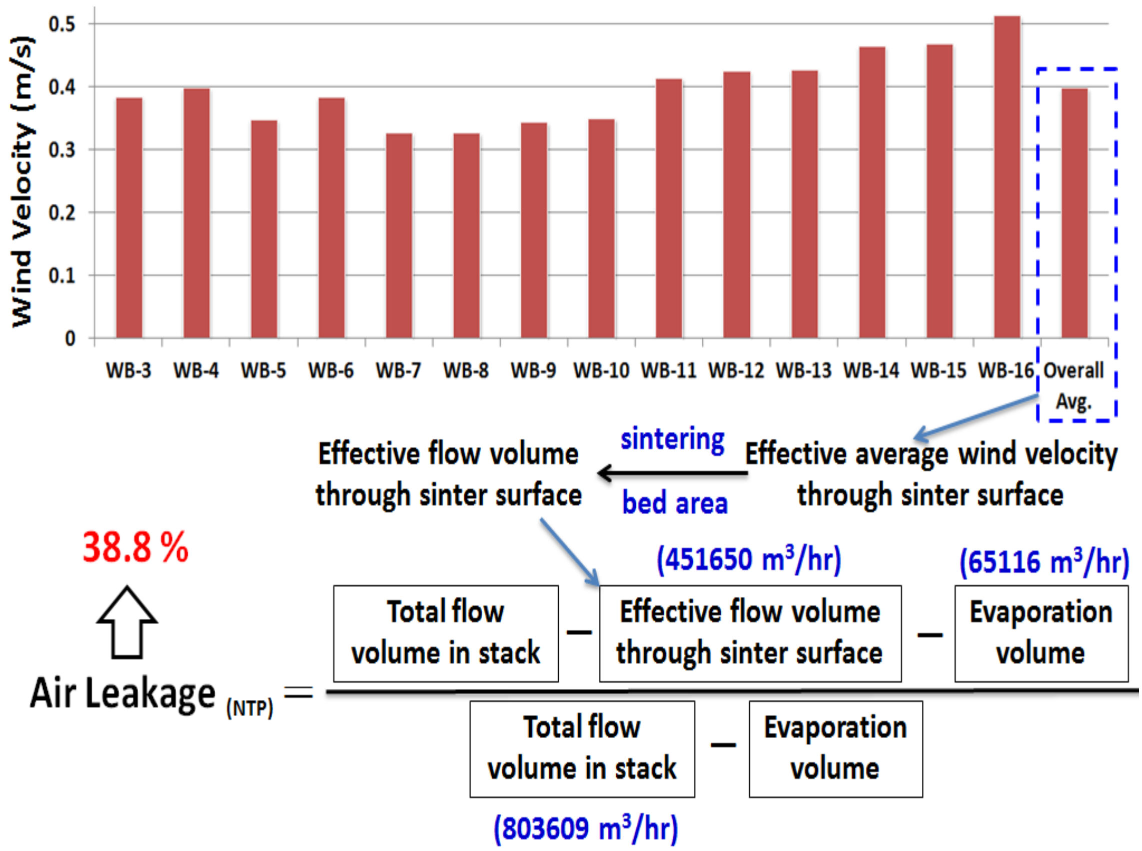


Fig. 7 A calculated instance of the air leakage rate in a sintering machine.

volume converted into the flue was 803,609 m^3/hr. For the volume estimation of water vapor, it showed the volume of water vapor 65,116 m^3/hr based on the raw material moisture content (7.2%), raw material crystal water ratio (7.92%), raw material bulk density (1,920 kg/m^3), pallet width (4.5 m), bed height (0.7 m), the pallet velocity (0.031 m/s), and the assumption of the mixture (50%) for a wet material in entire sintering process. A result of 38.84% for the air leakage rate of sintering system was obtained via the mass balance calculation, and finally, a real-time measured system for air leakage rate of sintering machine was developed.

3.1.2 Basic Theory and Test for Detecting Air Leakage of Sintering Pallets

The basic principle of air leakage detection on sintering pallets is according to the sound field analog equations of gas leakage, shown as Eqs. (3) and (4). It could be known from the formula that the sound pressure (P) of air leakage is proportional to the leakage aperture (D), that is, the air leakage is larger when the sound pressure is larger.

$$P(x,t) = k\rho u^2 MD \tag{3}$$

$$f = u / D \tag{4}$$

where, P: total sound pressure (Pascal, N/m^2); k: weighted constant; ρ: gas medium density; *f*: noise frequency; *u*: leakage rate (m/s); M: Mach number; D: diameter of leakage (mm). The microphones were used to test and compare the sound pressure of the old pallet and the new one in this study, respectively. As a result, it was found that the old pallet with more damages had a significantly higher sound pressure from low to high frequency (*f*), as shown in Fig. 8. Therefore, it confirmed the feasibility of using sound pressure of microphone for determining the amount of air leakage.

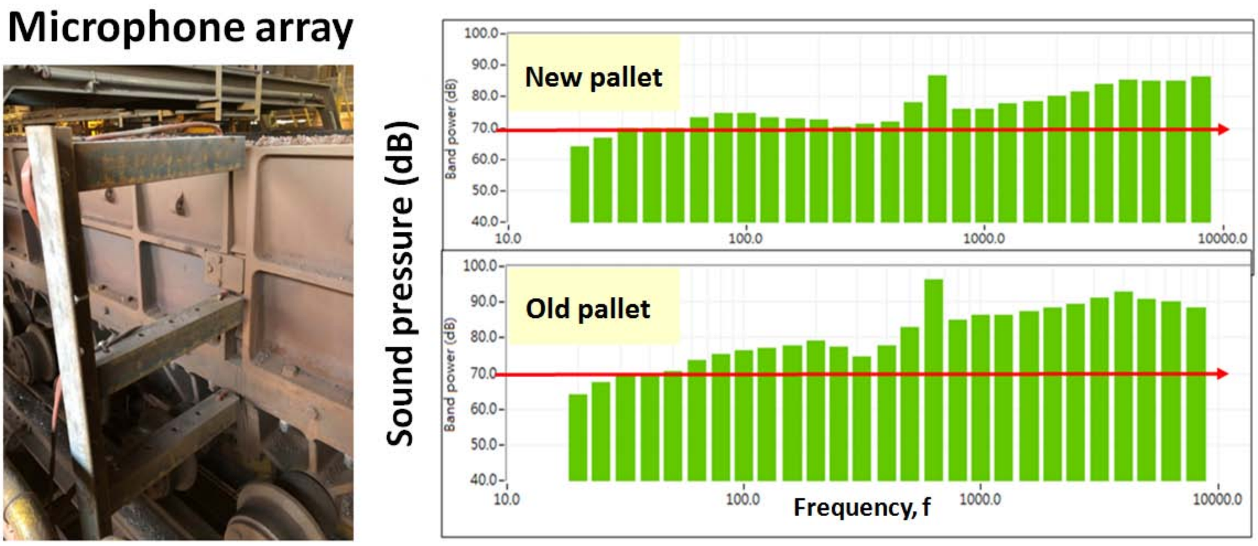


Fig. 8 Comparing test results of sound pressure in an old and a new pallet.

3.1.3 Application of the Automatic Ranking System and Its Verification

The ranking system of air leakage on sintering pallets was verified in this study, three (No. 137, 130, and 28) of the top few pallets in ranking list were substituted to the new three (No. 71, 30, and 84), and the results showed that the new three pallets did not enter the air leakage ranking list. From the observing and checking of removed three pallets, the severe pallets damage (air leakage) occurred such as grate bars damaged, pallets wall damaged, seal bars get stuck, as shown in Fig. 9, and it was successfully verified that the air leakage detecting system in this study was precise. Therefore, this system had the function of automatically providing the priority for maintaining the pallets, it can assist the staffs to conduct the actions on targeted maintenance for improving the air leakage of the pallets promptly, reducing the electricity consumption of the suction fan for the sintering machine, and increasing the stability of the sintering process.

3.1.4 A System Developed to Position Pallets for the Wind Velocity into the Sinter Surface

During the course of this study, it was found that if a larger amount of air leakage exists under a certain amount of fan suction, there was a less effective air volume flowing through the sinter bed. Based on this viewpoint, both the detection system for an effective air volume through sinter bed and the RFID sensor technology were combined to establish a system for positioning the pallets for the wind velocity into sinter surface in this research. It instantly presented the effective wind velocity with six positions for each pallet which are travelling to the middle section of sintering process, as shown in Fig. 10. Then the threshold value with lower wind velocity (a smaller effective air volume through the sinter bed) was set to be an assisted criterion for above mentioned ranking system on the air leakage rate of sintering machine.

3.1.5 A Ranking System of Air Leakage on Pallets with Sound Pressure and Wind Velocity

Finally, in combination with the criteria of sound pressure and wind speed, the integrated air leakage ranking system for pallets could be established to further focus on the selection of air leakage pallets which must be replaced as soon as possible, as shown in Fig. 11. According to the feedback from the users, this technology could assist in the operation inspection, maintain and repair judgment. It had been implemented in No. 2 sintering machine of China Steel Corporation (CSC) and extended to the remaining five sintering machines.

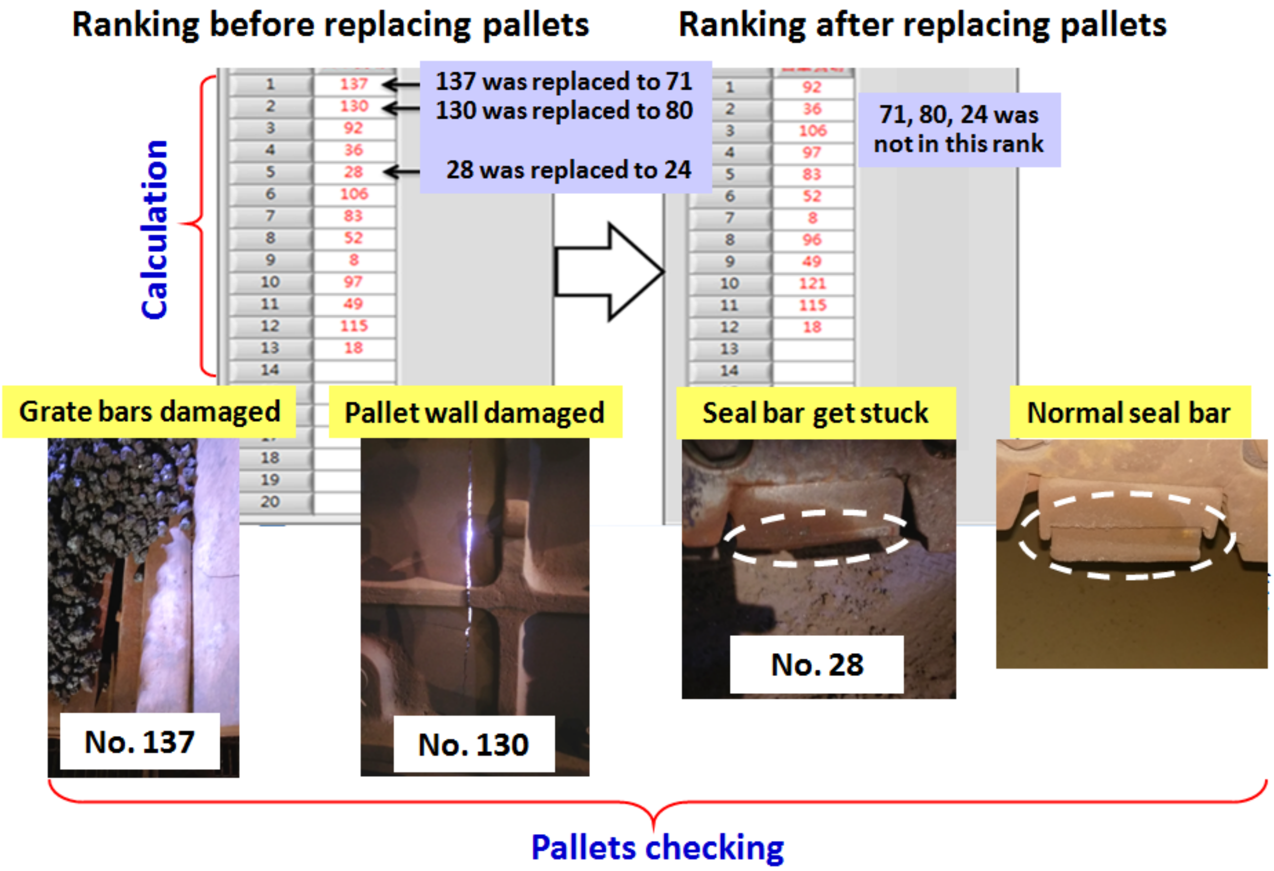


Fig. 9 Test results of the automatic ranking system and its verification.

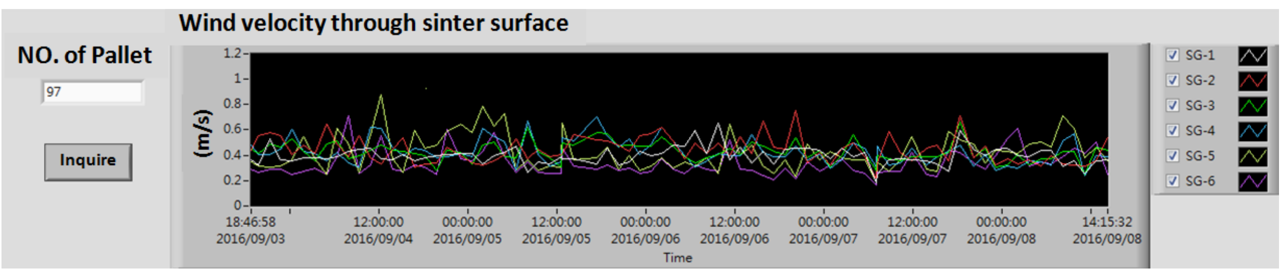


Fig. 10 The system screen for positioning pallets with the wind velocity into sinter surface.

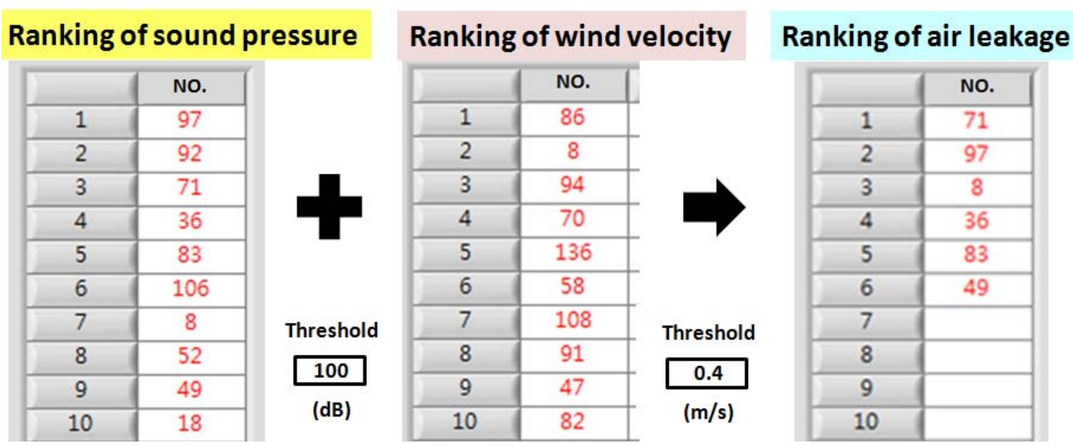


Fig. 11 The air leakage ranking on pallets with sound pressure and wind velocity.

3.2 Air Leakage of Dust Collectors

3.2.1 Conversion of Digital Signal and Differential Pressure

The range of direct current (DC) signal and differential pressure were 4-20 mA and 0-6,000 mmWC, respectively. The equation for the calibration curve is shown as following.

Differential Pressure (mmWC) = 375,000 × (DC signal) – 1,500 (5)

3.2.2 Analysis of Differential Pressure

The variation of differential pressure inside DCV is shown in Fig. 12. The absolute value of negative pressure inside top cone is lower when the air leakage in top cone has become more serious, and the value of differential pressure at "a" point in Fig. 12 is shown to be lower. The air leakage degree in top cone can be displayed as curve i and curve ii. Curve ii means a more serious air leakage has occurred in top cone because of the sudden decline of differential pressure. On the other hand, the negative pressure inside bottom cone is decreased due to the larger air leakage in bottom cone, and the "b" point in Fig. 12 also shows the lower differential pressure. Similarly, the curve iii and curve iv indicate the air leakage degree in bottom cone, curve iv shows a larger air leakage has occurred in bottom cone due to the sharp ascent of differential pressure.

Fig. 13 shows the diagram of variation of differential pressure inside DCV as a function of time in DCV operation cycle. It is time to take replacing DCV into consideration when either curve I or curve II occurs, or they both occur at the same cycle for a period of time. Therefore, the main criteria to judge the serious air leakage in DCV are enough low value of "a" point and "b" point in Fig. 13, in addition, curve I and curve II are also on the concave in Fig. 13.

3.2.3 Stability Test of Differential Pressure Gauge

The stability test was mainly to observe the signals decay of differential pressure after installing the pressure gauge for a period of time. Fig. 14 shows the comparison of initial measured data and the data after installing for six months, the result indicates the difference is insignificant, that means the sensor is not affected by dust pollution. It is also proved that the device can maintain its function under the conditions of dust and vibration inside DCV more than six

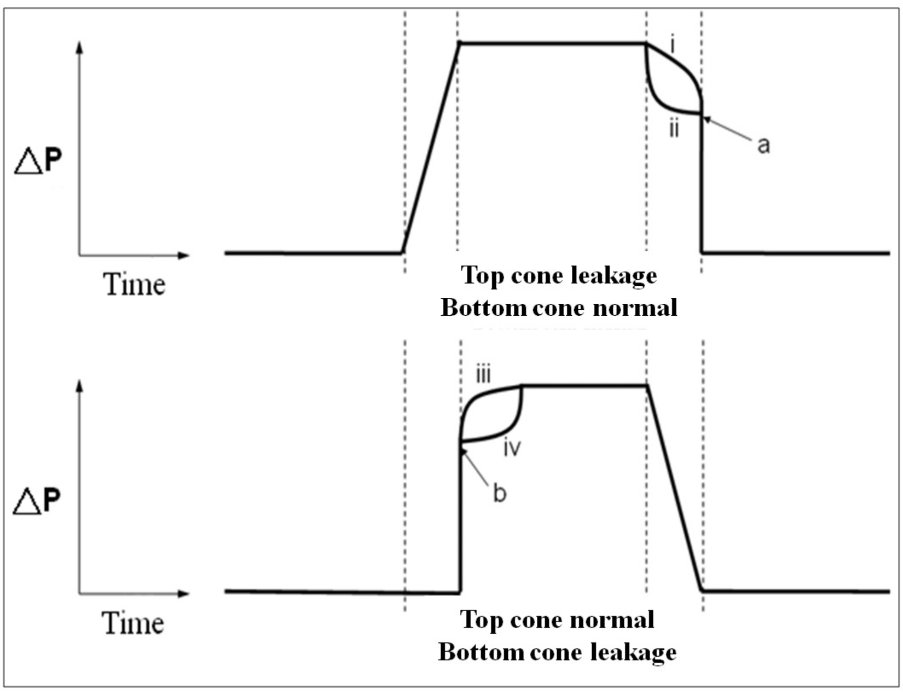


Fig. 12 Diagram of air leakage degree of DCV by observing pressure pattern.

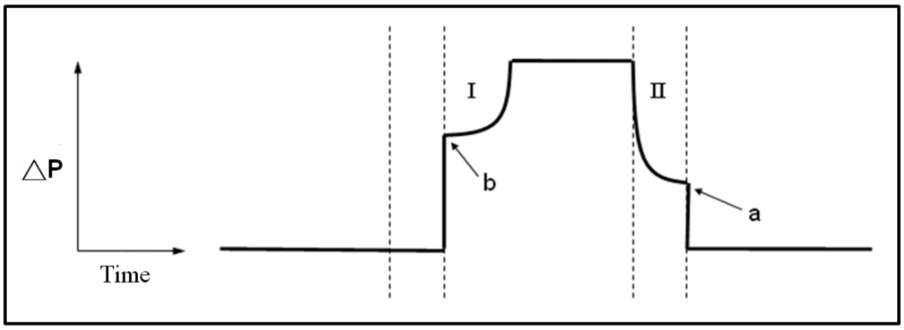


Fig. 13 Diagram of pressure pattern for judging the time to replace DCV.

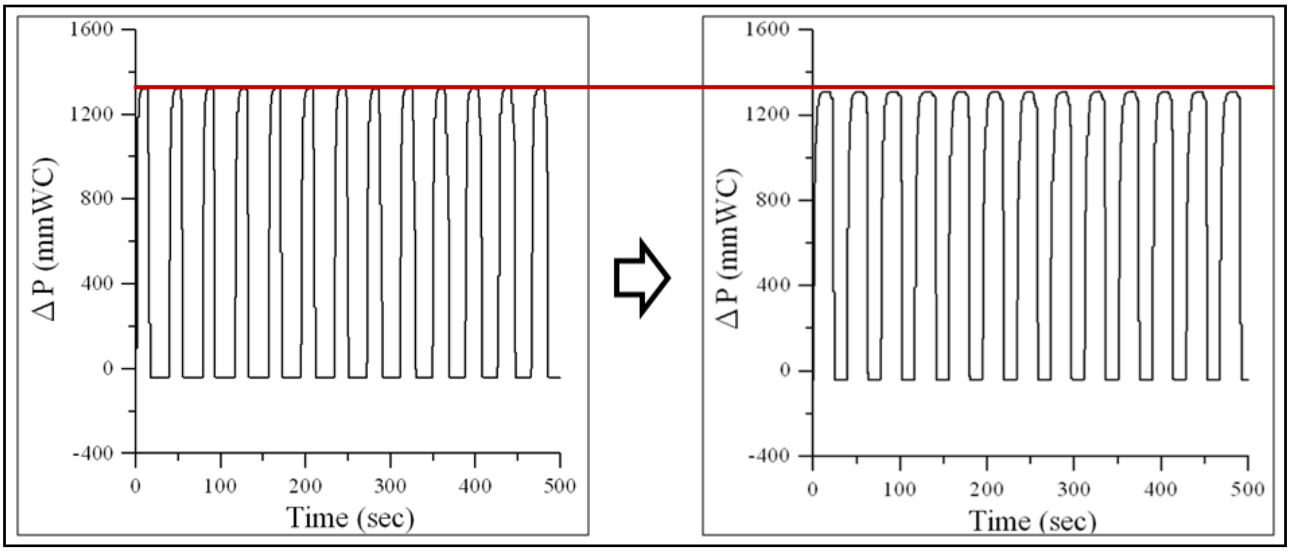


Fig. 14 Comparison of initial measured data with the data after installing differential pressure gauge for six months.

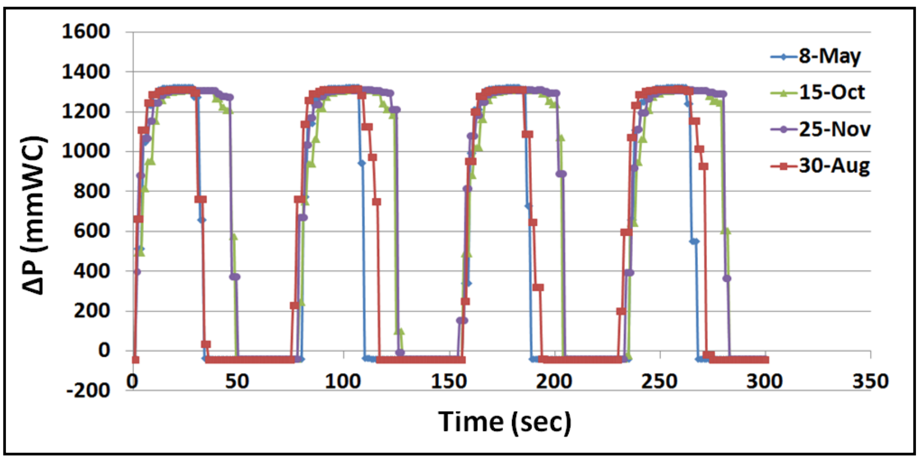


Fig. 15 Observation of six months measured data from May to November.

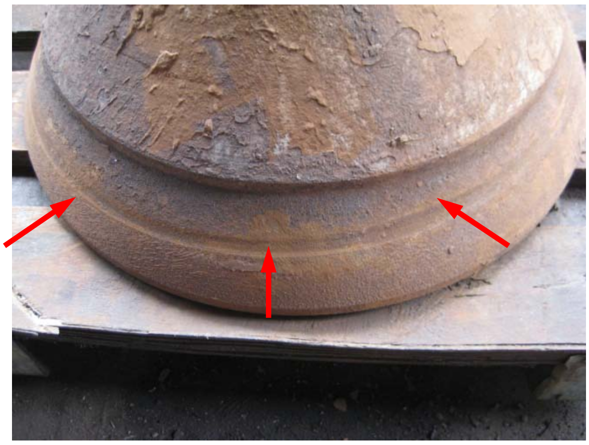
months. As the replacement cycle of DCV is three to six months, thus, the dust on the sensor inside DCV can be cleaned at the same time to resume the function of air leakage monitoring by reusing the differential pressure gauge.

3.2.4 Comparison of Actual Measurement and Theoretical Analysis

Fig. 15 shows the measured data from May to November, it illustrates that the pattern of differential pressure changes gradually with time, and the most obvious change is that the time of high differential pressure increases in per operation cycle. This measured result can be explained from the pressure pattern (III) in Fig. 15, which means the top cone has had an air leakage (It can be seen in curve 8/30, curve 10/15 and curve 11/25). As to the degree of air leakage, comparing the curve 10/15 and curve 11/25 in Fig. 7 with the pressure pattern (I) in Fig. 15, it demonstrates that the degree of air leakage inside top cone is more serious along with operation time.

3.2.5 Observation after Removing DCV

In order to understand what factors contribute to air leakage inside DCV, the DCV was removed to observe the surface of the cones when the pattern of differential pressure was appearing like the curve (11/25). Two cases can be found between the cone and its above contact ring, that is, mechanical abrasion or dust accumulation as Fig. 16. The main mechanism for air leakage was further investigated, the removed DCV (which was not cleaned) was reinstalled, then the water leakage was observed by pouring water from the top of DCV. Similarly, the case of cleaned DCV was also tested. The results displayed that both cases were obvious water leakage as Fig. 17, however, the latter case was more serious. It can be deduced that the main factor causing air leakage is the gap between the metal cone and metal ring due to the mechanical abrasion.



(a) Mechanical abrasion

(b) Dust accumulation

Fig. 16 Observations after removing DCV.

(a) Removed DCV is not cleaned

(b) Removed DCV is cleaned

Fig. 17 Observation of water leakage by adding water from the top of DCV.

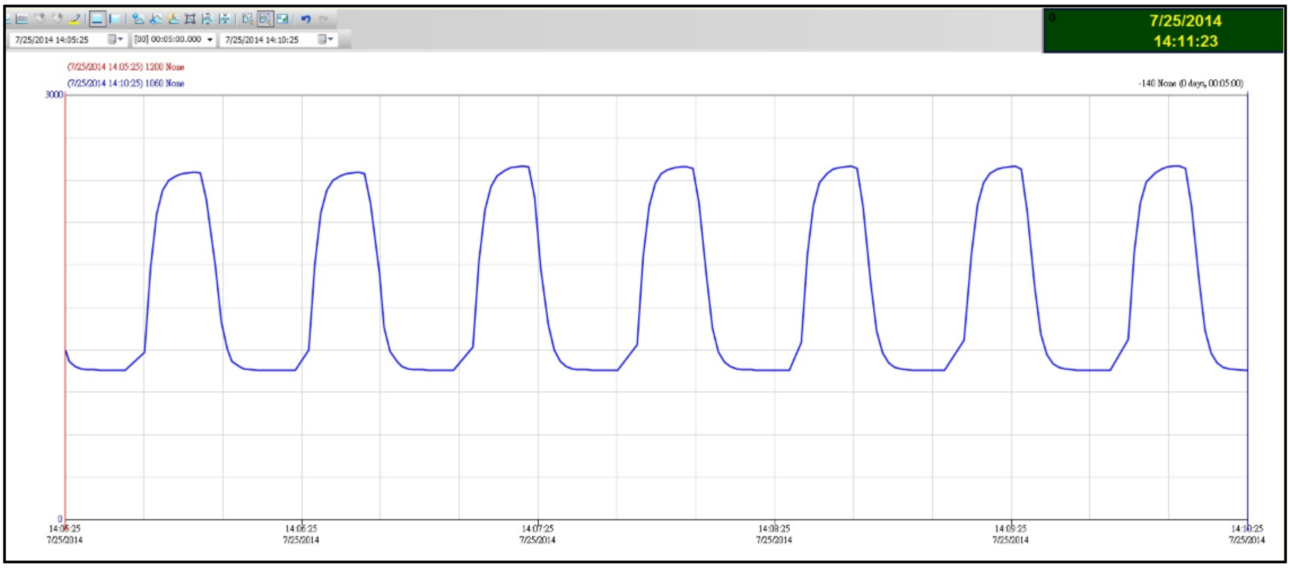


Fig. 18 On-line visualization for a long-term observation of differential pressure pattern in the sintering plants.

3.2.6 Criteria of Differential Pressure Pattern for the Timing of Renewing DCV

The real-time differential pressure had been connected to the control room of CSC No. 3 or No. 4 SP for visualizing an on-line and long-term observation of differential pressure pattern, as shown in Fig. 18. However, the differential pressure curve changes and qualitative criteria of the detection system are still not enough to provide on-site staffs an accurate determination of renewing the damaged DCV. Therefore, this study used the derivative signal of differential pressure with time (dΔP/dt) to identify the air leakage pattern of DCV, and a theoretical analysis result of (dΔP/dt) with the cycle action had been shown in Fig. 19. It proves that a significant difference on the peak magnitude could be sufficiently regarded as a judgment criterion when a air leakage occurs from DCV. When the two cone valves in the DCV are normal, the above and below peaks have the same size, and they both show the higher values; When the top cone valve is normal, and the bottom cone valve is air leakage, the above peak is greater than the below peak; On the other hand, the above peak is smaller than the below peak when the top cone valve is air leakage, and the bottom cone valve is normal; The size of above and below peaks is consistent, and they both show the lower values when the two cone valves in the DCV are air-leakage.

In order to verify above the theoretical pressure pattern analyzed from this work, the practical real-time data in sintering plant were directly used for comparison with the theoretical data, as shown in Figs. 19 and 20. It was proved that the actual data were consistent with the results of theoretical analysis proposed from this study from the cycle trend of the differential pressure signal changed with time in case that the top cone valve is normal, and the bottom cone valve is air leakage. This study set up the times of warning (e.g. *k* value) according to the different criteria of these DCV air leakage patterns, and the *k* was regarded as a predicting index while it reached the lower limited frequency of consecutive occurrences on any cases of abnormal differential pressure patterns.

3.2.7 Development of a Real-Time and Automatic Prediction HMI System [6]

This study built an HMI system with the automatic warning function by using the LabView program based on above mentioned warning criteria, and all parameters that showed how the severity of air leakage from DCV in the criteria of this HMI can be directly selected and adjusted by the staffs. This system would issue a light (or alarm) for reminding that the DCV had been significantly leaked currently

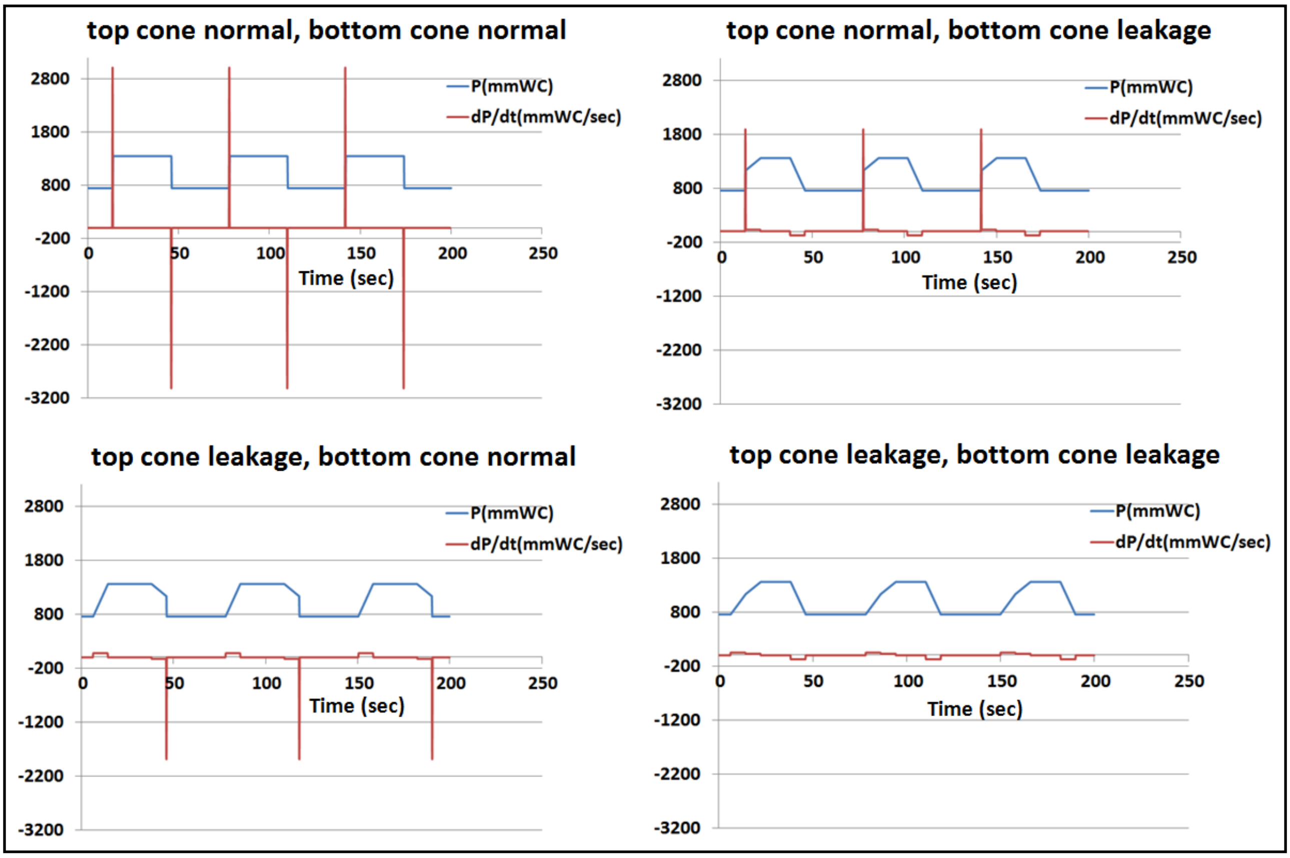


Fig. 19 Criteria of differential pressure pattern for the timing of renewing DCV.

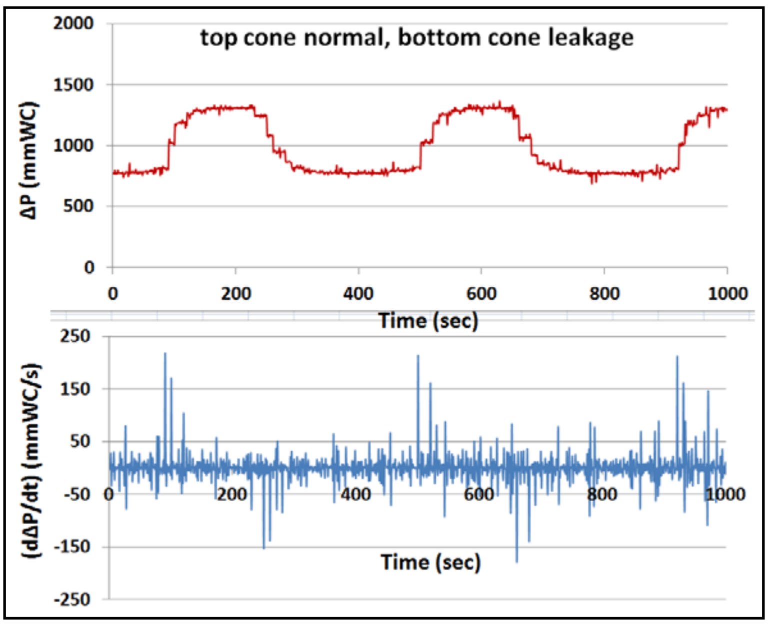


Fig. 20 Practical pressure pattern (ΔP) and its derivative signal (dΔP/dt) from DCV applied in CSC SPs (e.g. top cone normal, bottom cone leakage).

Date	2016.08.02	2016.10.03	2016.11.08	2016.12.22	2017.03.03	2017.09.14	2017.10.06
Air leakage rate	38.80%	41.50%	37.70%	35.90%	35.80%	37.66%	35.51%

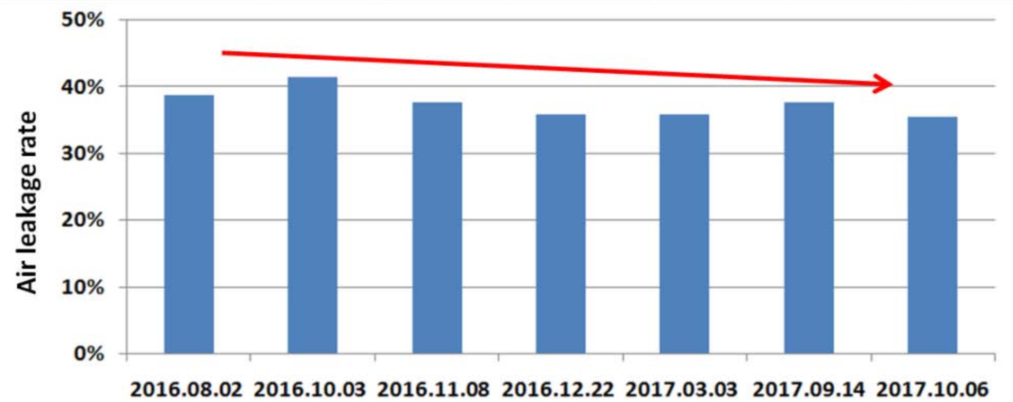


Fig. 21 The benefits of energy saving technology for lowering air leakage of sintering machine.

when the variation of differential pressure signal was in accordance with all criteria for one case or more cases of air leakage pattern, which could be instantaneously expressed that the *k* index had reached up a level of warning times. At present, this automatic predicting system for DCV air leakage has been applied to the electrostatic precipitator (EP) equipments in CSC No. 3SP and No. 4SP. It had provided staffs a simple and efficient tool for maintenance or renewing of DCV, and reduced air leakage to increase EP efficiency for avoiding the dust emission from the stack.

3.3 Achievements and Benefits

In this study, the energy saving technology for lowering air leakage of sintering machine was developed with the combination of a measurement system for the air leakage rate of sintering machine and an air leakage ranking on pallets with sound pressure and wind velocity. Furthermore, a capillary type of differential pressure gauge was used to examine the air leakage of DCVs, and the criteria for determining leaked DCV and the patterns for replacing the DCV were proposed to develop a detecting and predicting system for air leakage into dust collectors of sinter machine. It offers field staff a basis of maintaining or renewing DCV via a warning reminding and reducing air leakage to increase EP efficiency for improving energy saving and avoiding the dust emission from the stack. It had shown specific benefits, according to 14 months operational performance data from No. 2 sintering machine in CSC, the air leakage rate had dropped by about 5%, and the electricity current of the suction fan was reduced by 20 amps, which significantly reduced the sintering energy consumption and achieved the target of energy savings, as shown in Fig. 21. According to the literature, it indicated that air leakage rate of sintering machine reduced by 5%, the production increased by 3%, the energy consumption reduced by 1 kWh/ton-sinter, and the usage of fine coke decreased by 1 kg/ton-sinter [7, 8]. According to experience, the air leakage was decreased by 1%, the electricity consumption was reduced by about 0.15 kWh/ton-sinter, thus, the domestic and foreign sinter plant still dedicated to reduce the leakage rate of sintering machine.

4. Conclusion

In this technology, the hot-wire type anemometers were used for measuring the velocity of effective air flowing through the sinter bed, and the air leakage ratio of sintering machine could be calculated with the mass balance method to develop a detection system for the air leakage rate. Meanwhile, the microphones were installed beside the pathway and close to the outer sidewall of the travelling pallets for monitoring the sound pressure generated by the abnormal air leakage, and the thermal-resistant type RFID technology was adopted for identifying the travelling pallets. A ranking system was developed that the pallets with abnormal leakage can be detected and ranked in the severity of leakage according to the measured sound pressure and wind velocity with the relevant criteria.

In addition, the capillary type of differential pressure gauge was installed and long-time examined on the DCV below the EPs of sintering plants at CSC. The effective criteria to judge the serious air leakage in DCV were developed, and it was proved via the comparison of actual measurement and theoretical analysis, and the main factor causing air leakage was the gap between the metal cone and metal ring due to the mechanical abrasion. The predicting criteria and system for replacing the DCV had been proposed to offer field staff a basis of maintaining or renewing, and it was shown to promote EP efficiency and reduce the dust emission from the stack.

This technology had been implemented in the CSC No. 2 sintering plant and it could effectively reduce the air leakage ratio by 5% and further decrease the electricity consumption of the suction fan for the sintering machine.

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