Research on new type airtight material and airtight technology in silo

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Abstract
Acrylic acid paint, epoxy resin and non-saturated polyester resin are used respectively to carry out the airtight treatment for the silo. After the contrasting analysis of the solid silo at the work-site and indoor simulated system trial, it is considered that epoxy resin sealing material is better than the other two materials in respect of sealing effect and the convenience in construction. Good airtightness was reached with these sealing materials and contained about 32 minutes while the pressure reduced from 2500Pa to 2000Pa. The silo met the above-mentioned airtightness index can be effectively applied to fumigation for killing insect in atmosphere controlled grain storage. Ventilation can be done in silo and at the same time, the insecticides can be saved and treatment time can be shortened.

Proceedings
Silo is a kind of newly developed storage type in our national grain system. With the application and dissemination of the grain storage in silo, the corresponding subject regarding the silo high airtightness for fumigation to manage insect, atmosphere-controlled grain storage, ventilation has been brought about. Therefore, the study on sealing materials and corresponding technology in silo has been carried out in Tianjin Junliangcheng Depot of State Grain Reserves since 1984. One of test-using sealing material, i.e. acrylic acid paint was used in silo No 302 in Depot of State Grain Reserve successively in 1986. The pressure reached 50mm - 25mm water column, and half-life was 1’20". In 1994, the airtightness test used as the sealing material was carried out in wheat silo No. 21 in Depot of State Grain Reserve. The airtightness index was 1000Pa - 500Pa, and its half-life was 25‘48". Then, the epoxy resin was used as the sealing material in the silos No. 2 and No. 4 in Shenzhen Nantian Oil Industry Co. Ltd. in 1997. Its airtightness was better than that of non-saturated polyester resin. The pressure in silo reached 2500Pa - 2000Pa and could keep 32 minutes. The sealing test used above-mentioned materials was continued more years, and the different airtight effects had been met. Acrylic acid paint, epoxy resin, or non-saturated polyester resin was used in the indoor small test as the sealing materials by Tianjin Grain & Oil Research Institute, Storage Specialty Branch, in 1997. In view of these three kinds of sealing materials used as sealant for the airtightness reformation in silo. The contrasting analysis of the construction result between indoor small test and real silo at the work-site was carried out systematically.

The Trial Situation of Three Kinds of Sealing Materials in the Indoor Simulated Silo

The situation of indoor simulated trial silo
The indoor trial silo which is in the shape of square is used the brick & concrete structure, its net capacity is approximately 1m³, its wall thickness is 37cm. The reinforced concrete is poured onto the top, a pair of 500mm flanges are used at the manhole of the top. Top cover is used as the sealing head, two air intakes and one pressure inspection opening are installed at the sealing head. After the small trial silo is completed, the inside and outside of the silo are covered with one coat of cement.

Indoor simulated trial appliances and materials
Each one of U shape pressure gauge and gas pump, and a MK 245 stopwatch, the acrylic acid paint, non-saturated polyester resin, epoxy resin, polyurethane resin, the sealing cover, cement, the 107 glue, sand and so on were used.

Indoor simulated silo base pressure determination
The 8mm thickness rubber gasket sealing flange was used at the flange interface of the small trial silo's manhole, 28 bolts were used to fasten and then pressure air was filled in, the maximum preliminary pressure reached 6100Pa, and the airtightness half-life was 1000Pa - 500Pa. The pressure in silo kept 33 seconds.
The airtightness trial of the indoor simulated silo using acrylic acid emulsion paint

The acrylic acid emulsion paint has the characteristics of good water resistance, caustic resistance, drying quickly and strong adhesive force. It is non-poisonous, tasteless, non-flammable, non-explosive, and easy construction.

The airtightness trial method of the indoor simulated silo using acrylic acid emulsion paint

1.2:5 cement mortar was used to fill up the seam at the joint part of the top and wall of silo, and then the inside wall of the silo was covered with one coat of 107 glue. After it dried, the first coat of acrylic acid emulsion paint was painted. After 2–3 hours, manhole was sealed with the rubber gasket, pressure air was blew into the silo by air compressor for inspecting the airtightness. The inspection method of pressure half-life was used. The pressure in the silo was from 1000Pa to 500Pa. The results are listed in Table 1. After opening the silo's cover, the second and third coat of paint and determination of the half-life were carried out respectively according to the procedures mentioned above. The results are also listed in Table 1.

Table 1. The airtightness of indoor trial using acrylic acid paint, epoxy resin, and non-saturated polyester resin material.

<table>
<thead>
<tr>
<th>Material Type</th>
<th>1st determination 1000Pa–500Pa</th>
<th>2nd determination 1000Pa–500Pa</th>
<th>3rd determination 1000Pa–500Pa</th>
<th>Average value 1000Pa–500Pa</th>
</tr>
</thead>
<tbody>
<tr>
<td>One layer of acrylic acid</td>
<td>5'16&quot;</td>
<td>5'18&quot;</td>
<td>5'14&quot;</td>
<td>5'16&quot;</td>
</tr>
<tr>
<td>Two layers of acrylic acid</td>
<td>7'38&quot;</td>
<td>7'47&quot;</td>
<td>7'50&quot;</td>
<td>7'45&quot;</td>
</tr>
<tr>
<td>Three layers of acrylic acid</td>
<td>9'04&quot;</td>
<td>9'08&quot;</td>
<td>9'07&quot;</td>
<td>9'06&quot;</td>
</tr>
<tr>
<td>One layer of epoxy resin putty paste</td>
<td>78'51&quot;</td>
<td>78'13&quot;</td>
<td>78'08&quot;</td>
<td>78'24&quot;</td>
</tr>
<tr>
<td>Final coat of epoxy resin</td>
<td>92'18&quot;</td>
<td>91'52&quot;</td>
<td>92'25&quot;</td>
<td>92'11&quot;</td>
</tr>
<tr>
<td>The 1st step paint non-saturated polyester resin</td>
<td>25'09&quot;</td>
<td>25'29&quot;</td>
<td>25'18&quot;</td>
<td>25'18&quot;</td>
</tr>
<tr>
<td>The 2nd step paint non-saturated polyester resin</td>
<td>82'35&quot;</td>
<td>82'12&quot;</td>
<td>82'56&quot;</td>
<td>82'34&quot;</td>
</tr>
<tr>
<td>The 3rd step paint non-saturated polyester resin</td>
<td>83'27&quot;</td>
<td>82'52&quot;</td>
<td>82'57&quot;</td>
<td>83'05&quot;</td>
</tr>
</tbody>
</table>

Table 2. Property contrast of acrylic acid paint, epoxy resin, non-saturated polyester resin used as the sealing materials.

<table>
<thead>
<tr>
<th>Property/material</th>
<th>Epoxy resin</th>
<th>Non-saturated polyester resin</th>
<th>Acrylic acid paint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compound flavor</td>
<td>Good</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>Solidification speed</td>
<td>Better</td>
<td>Best</td>
<td>Good</td>
</tr>
<tr>
<td>Solidification shrink</td>
<td>Best</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>Stickiness</td>
<td>Best</td>
<td>Good</td>
<td>Poor</td>
</tr>
<tr>
<td>Hardness</td>
<td>Hard</td>
<td>Hard</td>
<td>Soft</td>
</tr>
<tr>
<td>Toughness</td>
<td>Good</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>Heat resistance</td>
<td>Best</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Medicine resistance</td>
<td>Best</td>
<td>Better</td>
<td>Better</td>
</tr>
<tr>
<td>Construction temperature</td>
<td>18°C</td>
<td>18°C</td>
<td>5°C</td>
</tr>
<tr>
<td>Construction humidity</td>
<td>85%</td>
<td>85%</td>
<td>85%</td>
</tr>
<tr>
<td>Base requirement</td>
<td>Neat dry</td>
<td>Neat dry</td>
<td>Neat dry</td>
</tr>
<tr>
<td>Material price</td>
<td>85RMB/m²</td>
<td>80RMB/m²</td>
<td>65RMB/m²</td>
</tr>
<tr>
<td>Time</td>
<td>10 years</td>
<td>10 years</td>
<td>3 years</td>
</tr>
<tr>
<td>Airtightness effect</td>
<td>32&quot;</td>
<td>25&quot;</td>
<td>1&quot;</td>
</tr>
<tr>
<td>Material density</td>
<td>1.8g/m³</td>
<td>1.2g/m³</td>
<td>0.2g/m³</td>
</tr>
</tbody>
</table>
The airtightness trial in the simulated silo using acrylic acid emulsion paint

- Because the acrylic acid emulsion paint is water soluble mixture, it should be mixed evenly just before using.
- When in construction, water content required for painting cement mortar should below 10%.
- The temperature required for construction should be above 5°C. When the temperature reaches at 25°C, the re-painting interval should be 2~3 hours.

The airtightness trial in the simulated silo using epoxy resin sealing materials

The epoxy resin has the superior characteristics of stickiness, corrosion-resistance, shaping quality, heat stability, wear-resistance, mechanical heat-resistance, and containing agents for corrosion-resistance.

The trial method of indoors small trial using epoxy resin

After removing the coat of acrylic acid paint on the inside wall of the small trial silo, the original cement surface must be treated and polished. Then the manhole was sealed and pressure air was blown. The preliminary airtightness half-life was from 1000Pa to 500Pa. It took 11". Epoxy resin and acetone were mixed fully and the solidified agents were added in according to certain proportion and mixed, the quantity of the compound should not be too much. The wooden brush was used to carry out the first time of painting and the job should be done evenly and quickly. After 6 hours of solidification, the manhole was sealed and the airtightness was determined, for the result seeing Table 1. Opening the manhole, the second time for sealing job was carried out. Epoxy resin, acetone, fossil powder, solidified agent were used to make epoxy resin putty according to certain proportion. The rubber plate was used to smear the inside wall of the small trial silo with putty for once, one coat of resin should be painted according to the first compound proportion, then one layer of nylon cloth was pasted at once. After 6 hours of solidification, manhole is sealed and airtightness is determined, half-life (Pa) is from 1000Pa to 500Pa. The result of test is listed in Table 1. For the third step, the manhole was opened and painting job was done according to the procedure as the first stage. After 6 hours for solidification, the manhole was sealed again and the airtightness was determined, for result seeing Table 1.

The keys for using the epoxy resin in the indoors small trial

- The wall body of silo should be dried fully, dust should be removed from the surface of wall before painting.
- It should be prohibited to get cement mixture too much one time.
- The ambient temperature should be above 15°C and the humidity should not be over 85%.
- The interval for repeat painting should be 6 hours in 15~20°C.

The airtightness trial in simulated silo using non-saturated polyester resin material

The non-saturated polyester resin has the characteristics of corrosion-resistance, caustic-resistance, anti-water, strong stickiness, and high intensity, but poor shock-resistance.

The trial method of the indoors small trial using non-saturated polyester resin

First of all, the epoxy resin coat was to be removed, then the cement mortar was applied to make level. A curing period of 15-day is necessary. After the thorough ventilation and drying, manual-pasting method was used in the construction. During construction, the key is that a thin coat should be done evenly. The non-saturated polyester resin, promoter, solidified agent were mixed in according to certain proportion. After 24 hours for complete solidification, the manhole was sealed and the airtightness was determined. The result is listed in Table 1. Then the second step of sealing was done with the resin-glass fiber reinforced plastic glue was used. Resin, filling, promoter, and solidified agent were mixed according to certain proportion. After the small trial silo was smeared with the glue, A lining cloth should be painted with brush at once. Accordingly, a coat of glass cloth is pasted, then another layer of lining cloth was painted, getting the glass cloth soaked through, and second layer of glass cloth was pasted. After solidification for 24 hours, the manhole was sealed again. The airtightness data is listed in Table 1. In the third step, the manhole was opened, then a coat of resin was painted. After 24 hours, the manhole was sealed again and the airtightness is determined. The result is listed in Table 1.

The important points for non-saturated polyester resin sealing small trial silo construction

- The sequence for pasting the glass cloth was as follows: the elevation is the first, the plane is the second, and the part is the first and the surface is the second. The sequence in elevation pasting was from top to bottom.
- The width of the glass cloth’s overlapped part should not be less than 50mm. The overlapped part of different layer should be staggered mutually.
- During construction, scraping plate and brush should be used to paste and press the glass cloth firmly. Be sure to squeeze out the included bubble and surplus glue.
- It is not suitable to mix too much resin, solidified agent and glue materials. The mixed material should be used up within 30 minutes.

The Trial in the Real Silo Using Different Sealing Materials

The airtightness trial in silo using acrylic acid paint

Materials and method

The trial was carried out in silo No 302 in Depot of State...
Grain Reserve  The silo is 7 meters in diameter, 35mm in height and 27 meters in grain loading height. The capacity is approximately 1300m³. It is made of reinforced cement. The body of silo was built by means of sliding-form technology. The prefabricated components were used to cover the top. The ducting system for grain unloading opening at the lower part of the silo was made of steel plate. Because the sealing requirement for the fumigation is not considered when this silo was built, there is a great deal of seam between the body and top cover of silo, and air among silos can change through the seam. There are also tiny holes between grain unloading opening and body of silo. During the trial, one coat of 107 glue was painted onto the inside of the silo. After it was dried, one coat of 1 2 5 cement mortar was applied, then a coat of white cement was applied. One coat of cement mortar is applied over the white cement coat. The final coat was acrylic acid paint. Rubber gasket was used for sealing the grain unloading opening.

After the sealing treatment to silo was finished, the airtightness examination was carried out. The pressure half-life examination method was used. Pressure in silo was set up to 50mm water column, and then water column was reduced to 25mm water column, the half-life was 1'20". It proved that the silo had better airtightness, and it was suitable for fumigation insect killing.

The keys for construction

- Before construction, the dust at the base should be cleaned up, the bumps and hollows should be filled up.
- 107 glue is water-soluble, thus in painting operation, water should be added for diluting the paint.
- The seam of the cement layer should be plastered smoothly and painted thickly.
- The ventilation equipment should be installed in the silo and remove the acrylic acid smell.
- The cement layer must be maintained for 15 days. After the curing period, the acrylic acid paint can be painted.
- The temperature should be above 15°C for construction, and the humidity should be below 85%.

The airtightness trial in silo using epoxy resin sealing materials

The trial materials and methods

The airtightness trial using epoxy resin material was carried out in No 2 material supply silo Shenzhen NanTian Oil Industrial Co., Ltd. It is 10m in diameter and 40m in height, and its capacity is 3000m³. The structure is of reinforced cement and body of silo was built by means of sliding-form technology. Because the sealing requirement for the fumigation was not considered in construction, there is a lot of seam between the body and top cover of this silo. As well as a few mould plates and iron pipes on the top cover have not been removed. Air is able to flow from a silo to others. Therefore, it can not be used for fumigation. The modification has to be done to meet the airtightness condition. For the sealing the silo, first of all, 1 2 5 cement mortar was used to fill up the seam. Cement mortar was used to make level 2 meters below the top onto the inside wall of this silo. After 14-day maintenance, one coat of epoxy resin was painted. The solidification took 6 hours. One coat of epoxy resin putty was smeared, one coat of epoxy resin was painted afterwards, and then a layer of polyester fiber cloth was pasted. The interface thickness should overlap about 3cm. After another 6-hour solidification, another coat of epoxy resin was painted. After sealing was finished, fumigation ventilation circular flow ducting system should be laid. Butterfly valve was used to control the grain unloading opening. Grain intake opening and dust-removing opening, pressure vessel cover was used for the manhole sealing, and it reached the airtightness. Airtightness inspection was carried out. Pressure inspection method was used in this silo, it took 32 minutes that the pressure in silo was reduced from 2500Pa to 2000Pa. Thus a silo with good airtightness was proved and used for fumigation the grain stored in controlled atmosphere.

The keys for using epoxy resin material in construction

- The first coat of epoxy resin used for foundation laying has the function of strengthening the stickiness, but the dust on the wall inside silo must be cleaned. The inside wall of silo should be smooth and dry.
- During the construction, there must be no bubble under the polyester fiber cloth. The scraping plate and glue rollers should be used to scrape and press out all of bubbles from coat carefully and firmly.
- It is not suitable to mix too much at a time. The pasting operation should be finished within 40 minutes.
- The suitable temperature for construction should be 15-25°C. The relative humidity should not be higher than 80%.

The airtightness trial in silo using non-saturated polyester resin sealing material

The trial is carried out in No 21 brick silo of Depot of State Grain Reserve. The silo is 16.4m in height, 6.36m in outside diameter, and 5.8m in inside diameter. The silo's top is of pre-fabricated component, flat, and its bottom is of concrete cone shape. There was air leaking at connecting part of the silo's body and grain unloading ducting system.

Material and methods

For the airtightness of silo, dust on the inside surface of wall and top inside the silo should be removed thoroughly. Cotton yarn was used for cleaning. White cement was smeared on the top of silo two times. 1 2 cement mortar was used to make level two times. One coat of non-saturated polyester resin was painted from the bottom of the inside wall of the silo according to proportion. The tailored glass fiber cloth should be pasted onto the resin before
solidification. Scraping plate was used to scrape for smoothing. The above-mentioned operation was repeated, then one coat of well-mixed resin was painted and polyester film was pasted in given order. Scraping plate was used to scrape smoothly. After solidification of non-saturated polyester resin, polyester film was taken away, thus a whole body of 2mm glass fiber reinforced plastic layer was formed at the surface of the inside wall. After airtightness modification was done at the silo cone bottom, the grain outgoing opening, and the manhole, a set of 4 - 19 - 4 centrifugal fan was installed to supply pressure to the silo, the pressure half-life from 980Pa reduced to 490Pa was 25'48'.

The contrast analysis of three kinds of sealing materials used for airtightness modification

By comprehensive analyses of airtightness using 3 kinds of sealing materials (acrylic acid paint, epoxy resin, and non-saturated polyester resin), if the procedure and method are properly arranged and strictly obeyed by different linking-up, the desirable airtightness effect can be reached with the above mentioned materials. After finishing the indoor trial and field test in real silo, we concluded that the airtightness of silo sealed with above-mentioned materials could meet the requirements for fumigation to kill insects in stored grain, could reduce the cost in grain preservation. The grain transportation links and expenses can be saved.

In 1997, the systematic indoor trial used acrylic acid paint, epoxy resin, non-saturated polyester resin three kinds of sealing materials was carried out in our laboratory. By the comparative study on heat deformation temperature, wear and tear, shock intensity, cut intensity, stretch intensity, it was considered that the hardness of acrylic acid paint was poor and the paint containing non-saturated polyester resin has strong smell which is not suitable for the construction in silo. The epoxy resin is a desirable sealing material. In 1997, the epoxy resin was chosen as sealing material for sealing circular pipes installed in a silo of Shenzhen Shekou Nantian Oil Industry Co. Ltd. The effect of construction was satisfactory. The acceptance test was carried out by Tianjin Synthetic Material Industrial Research Institute. The data are as the following: heat deformation temperature is 47°C, wear and tear is 1.5436g/km, shock intensity is 3.0kJ/m², cut intensity is bigger than the stretch intensity of the tile.

References

The controlled atmosphere storage and atmosphere-controlled warehouse (in Chinese), Machinery industry publishing house.