Research and establishment of steam dryness detection method

Yusheng Wu 1, Chunyuan Zhang 2, Jichun Qian 1, Junhui Wu 2, 3 *

1Equipment Management Department Xiamen Tobacco Industrial Co., Ltd. Fujian, China
2Institute of Modern Agricultural Science & Engineering Tongji University Shanghai, China
3Author to whom any correspondence should be addressed
E-mail: junhui_wu@163.com

Abstract: In this paper, by designing the overall idea of the pipeline steam dryness control measurement system, designing and implementing the pipeline steam dryness control measurement system, constructing the pipeline steam dryness control measurement test platform, integrating the pipe steam dryness control measurement system and the effect verification, studying and establishing the steam dryness detection method to improve the application effect of steam in the tobacco processing process.

1. Introduction
Steam is widely used in the key processes of tobacco production line, and the tobacco industry focuses on the improvement of equipment performance by reducing the transformation of steam belt water, energy saving and consumption reduction, and the impact of steam quality on equipment performance and production efficiency. [1-2] The normal operation of tobacco production line equipment and product quality have a great relationship with steam quality, good steam quality can not only improve the utilization rate of energy, but also effectively extend the service life of valve parts and equipment. The improvement of the steam application effect for the wire production line is one of the important means to improve the quality of tobacco.[3-4] The overall research about application of steam dryness and overheating detection methods in the tobacco industry, the index and method of steam chemical quality testing, the study of the relationship between steam quality and equipment performance and product quality, etc., in the industry is not deep enough.[5]This paper is aim to improve the application of steam in the cigarette processing process through the study and establishment of steam dryness detection method. [6-7]

2. The overall design idea of the pipe steam dryness control measurement system
In order to accurately measure and adjust the steam dryness of the pipe, so that the steam dryness of the key process of tobacco making is in a reasonable range, the pipe steam dryness control measurement system is designed, as shown in Figure 1. The system is made up of a steam generator, a humidification device, a dehumidifier, a gas collection tank, a dryness meter and a supporting steam pipe, which enables steam humidification, steam dehumidification, different proportions of wet and
dry steam mixing, and mixed steam pressure, flow, temperature, density and dryness of the combined measurement and other functions.

![Figure 1. Pipe steam dryness control measurement system.](image)

The saturated steam produced by the steam generator is divided into three branches: the steam in branch 1 enters the gas collection tank directly through the pipe and valve. The steam in branch 2 enters the humidification device, and after the dryness is reduced, the wet steam obtained enters the gas gathering tank. The steam in branch 3 enters the dehumidification devices, and after the dryness is increased, the drier steam obtained enters the gas gathering tank. In order to prevent backflow of steam in different pipe sections due to different pressures, check valves are installed in branch 2 and branch 3. Dry and wet steam is fully mixed and buffered in the assembly tank, measured by the steam dryness meter and enters the steam equipment. Branch 1 is in a normal state, branch 2 and branch 3 only one open. According to the dryness meter measured steam dryness, switch branch 2 and branch 3, and adjust the flux volume through the valve, while adjusting the steam volume of branch 1, so as to realize the mixing of dry and wet steam with different proportion and obtain the mixed steam with different dryness.

3. Design and implementation the control measurement system of the steam dryness in pipes

3.1. Design scheme of combined online pipeline steam dryness meter

According to the current situation of the production process in the key section of wire making, considering the measurement margin, the effective detection range of the measuring instrument is determined, which is listed in Table 1.

| Measurement stake                  | Range     |
|------------------------------------|-----------|
| Pressure before decompression (MPa)| 0.8-1.5   |
| Stress after decompression (MPa)   | 0.2-0.6   |
| Mass flow (kg/h)                   | 100-800   |
| Temperature (°C)                   | 100-180   |
| Dryness (%)                        | 70-100    |

According to the measurement principle of double vortex joint method, a combined online pipeline steam dryness meter is designed to realize the joint measurement of pressure, flow, temperature, density and dryness of wet saturated steam, as shown in Figure 2.
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Figure 2. Structure diagram of combined online pipeline steam dryness meter.

The combined online pipeline steam dryness meter is made up of horizontal straight pipe segment, mixed-phase rectifier, vortex street sensor I, vortex street sensor II, temperature sensor, pressure sensor, front and rear side flange, and is installed in the steam horizontal straight pipe segment. The technical options used are:

1. Steam Mixed Phase Rectifier
   The upstream end of the pipe wall is equipped with a mixed rectifier, which accelerates the flow of vapor-liquid mixture, and forces the flow of the fluid in a certain direction, so that the vapor-liquid two-phase forms a uniform mixture, and there is no relative slip between the phases. When a two-phase fluid passes through the device, the two-phase flow does not change, and the gravity of the two-phase fluid and the friction force generated by the device can be ignored. At this point, two-phase fluids with the same temperature and saturation at high temperature and high pressure can be studied as a single-phase fluid.

2. Steam Temperature Measurement
   There are two ways of temperature measurement: thermocouple and thermal resistance. Combined with this process, the thermal resistance thermometer is used in the dryness meter to measure the steam temperature, depending on the steam temperature range from 100 to 180 degrees C.

3. Steam Mass Flow Measurement
   In the process of measuring volume flow by using the vortex flow meter, the vortex signal is ignored as another kind of information contained in the "rich flow field information source" which contains a large amount of flow information, i.e. the vortex signal amplitude. In fact, the size of the vortex street signal is not only related to the flow rate, but also closely related to the density of the fluid. That is, the vortex signal contains two kinds of information: one is the information representing the flow rate \( v \), the characteristic quantity is the vortex shedding frequency \( f \), the other is the information representing the mass velocity \( v \), the characteristic quantity is the vortex signal amplitude \( P \). Taking full advantage of these two types of information, the vortex street sensor can achieve the measurement of mass flow through the necessary information processing, the measurement step is shown in Figure 3.

![Figure 3. Measurement of saturated wet steam mass flow by vortex flow meter.](image-url)
Combined with this process, the steam mass flow (or density) is measured in the dryness meter by going through the second vortex flow meter.

4. Experimental platform for regulating and measuring the dryness of pipeline steam

According to the results of the study, the design of the experimental platform has been completed and the experimental test is carried out. The operating function parameters of the experimental platform are listed in Table 2.

Table 2. The range of measurement items of the pipeline steam dryness control measurement test platform.

| Measurement Stake | Range   |
|-------------------|---------|
| Pressure (MPa)    | 0.2-0.6 |
| Flow (kg/h)       | 25-100  |
| Temperature (°C)  | 80-180  |
| Dryness (%)       | 30-100  |

4.1. Steam generator

A steam generator (commonly known as a boiler) is a mechanical device that uses heat from fuel or other energy to heat water into hot water or steam. In the pipeline steam dryness control and measurement platform, the model ldr0.1-0.7 electric heating steam generator is used to generate steam with rated pressure of 0.7MPa and rated flow of 100kg/h.

4.2. Dehumidifier

For the mixed water steam produced from the boiler in the state of two-phase coexistence of steam and liquid, the use of adsorption dehumidification can achieve the purpose of high efficiency filtration of water foam. Commonly used adsorption and dehumidification equipment are screen type demister, folded plate type demister and steam water separator. Compared with the screen type demister, folded plate type demister and steam water separator, because of the high separation efficiency (dryness up to 99%) and convenient installation (pipeline connection, hanging installation) of the steam water separator, it is determined to use the steam water separator as the dehumidification device of the tobacco production line. Steam water separator is a kind of steel pressure vessel, which is used to remove liquid drop in steam system or compressed air system. The separated liquid is discharged through the drain valve, and the dry and clean steam is discharged from the separator outlet. The structure of steam water separator is shown in Figure 4. There are three types of separators in the steam system: baffle type separator, spin type separator and adsorption type separator. Due to the wide range of steam flow rate in the pipeline, the separator with a wide range of flow rate application, namely baffle type separator, is selected. In this experiment platform, the baffle type steam water separator of AS7-16c is used for steam dehumidification.

Figure 4. Structure diagram of steam water separator.
4.3. Humidification device

At present, there are two ways to realize the humidification of pipeline steam, namely, the humidification of steam ejector and the humidification of Desuperheater. Through literature search, it is known that the desuperheater has been used in the silk production line, and the method is simple in structure, sensitive in temperature regulation and easy to realize automation. Therefore, the new type of spray desuperheater is selected for the experimental platform to humidify the steam. See Figure 5 for the structural diagram of the new spray desuperheater.

![Figure 5. Structural diagram of new type spray desuperheater.](image)

The Desuperheater of the experimental platform is customized according to the flow, pressure and pipe diameter, that is, the flow is 25-100kg/h, the pressure is 0.2-0.6mpa, the pipe diameter is DN25, and the regulation principle of steam dryness is shown in Figure 6.

![Figure 6. Schematic diagram of steam dryness regulation.](image)

4.4. Gas tanks

The gas gathering tank gathers the steam of three branches, and the dry and wet steam are fully mixed and buffered in the gas gathering tank and then led to the steam equipment. The gas gathering tank is customized according to the pipe diameter, steam pressure, flow and storage capacity, and the internal baffle and wire mesh are set to fully mix the steam.

4.5. Steam pipes and accessories

Because the pipeline transports low-pressure steam, non-toxic and non-corrosive, the standard GB/T 3091-2001, i.e. welded steel pipe for low-pressure fluid transportation, is selected. There are three kinds of pipe materials available: q195-a, q215a and q235-a. because of the high strength of Q235-A, the pipe material is q235-a. Determination of pipe diameter: under the flow of 100kg/h and pressure
of 0.6MPa, select the common flow rate of pipeline steam, then calculate the pipe diameter according to formula (3), and check the corresponding standards to determine the pipe diameter. The nominal diameter is DN25, the outer diameter is 33.7mm, the wall thickness is 3.2mm, and the inner diameter is 27.3mm.

\[ Q_m = \frac{3600 \pi d^2 u \rho}{4} \quad (1) \]

Check: According to the selected tube diameter, formula (4) and formula (5), the flow rate \( u \) is 15m/s, the Reynolds number \( Re \) is 90614, the flow type is turbulence, and according to the estimated tube length, the pressure drop is calculated to meet the permissible pressure drop. Therefore, the tube diameter selection is appropriate.

\[ u = (18.81)^2 \frac{Q_m}{(\rho d^2)} \quad (2) \]

\[ Re = \frac{\rho u d}{\mu} \quad (3) \]

5. Integration of pipe steam dryness control measurement system

Through the selection of various equipment, pipes, pipe fittings and valves of the pipeline steam dryness control and measurement system, a detailed pipeline steam dryness modulation measurement system is established, as shown in Figure 11. The system is composed of steam generator, desuperheater, steam water separator, gas collecting tank, dryness meter, signal controller and supporting steam pipes. It can realize steam humidification, steam dehumidification, dry and wet steam mixing of different proportions, and measure the pressure, flow, temperature, density and dryness of mixed steam. The dry and wet steam shall be fully mixed and buffered in the steam gathering tank, and shall enter the steam equipment after being measured by the steam dryness meter. A dryness meter is installed on the outlet pipeline of the gas gathering tank, which can measure the pressure, flow, temperature, density and dryness of the saturated steam, and transmit the processed dryness, flow, temperature and other signals to the signal controller. By comparing with the preset dryness, flow and temperature signals, the feedback signals are respectively sent out to control the electric control valve, adjust the flow of each branch, and make the transmission of the dryness, flow and temperature of the steam can meet the requirements, so as to realize the automatic detection and control of the dryness.

![Figure 7. Steam dryness modulation measurement system.](image-url)
Build a Steam dryness modulation system according to Figure 7. There are two channels in the system: one is composed of branch 1 and branch 2, the main purpose is to reduce the steam dryness, one part of the steam from the steam generator is cooled or heated directly through the desuperheater, the other part is connected to the gas gathering tank and join the steam from the desuperheater; the other is composed of branch 1 and branch 3, one part of the steam enters the steam water separator to improve the dryness of the steam, and join the steam from the steam generator, so as to get a dry steam. The steam from the gas gathering tank shall be measured by a dryness meter before entering the steam equipment. Branch 1 is in a normal open state. According to the measured steam dryness value of the dryness meter, switch branch 2 and branch 3, and adjust the steam flow through the valve to realize the mixing of different proportion of steam dryness, so as to obtain the mixed steam with different dryness.

6 Effect Verification
Test purpose: As a mature equipment, the results of off-line dryness tester are widely recognized. By comparing the results of off-line and on-line dryness tests, including the trend consistency and result consistency of data, the accuracy of on-line dryness tester is verified.

Test method: By the condition of stable steam pressure and dryness, and the condition of different dryness gradients, the off-line and on-line dryness detection instruments were used to detect five groups of dryness, and the difference between the on-line and off-line dryness test results was compared to verify the data reliability of the on-line dryness instrument developed by the project team. See Table 3 for specific design.

| Gradient  | Gradient I | Gradient II | Gradient III | Gradient IV | Gradient V |
|-----------|------------|-------------|--------------|-------------|------------|
| Set steam pressure/bar | 1.6 | 1.9 | 1.8 | 1.8 | 2.4 | 2.4 | 2.4 |
| Steam flow/kg.h⁻¹ | 39.5 | 39.8 | 38.1 | 39.5 | 39.6 | 39.8 | 39 | 39.4 | 39.2 | 39.7 |
| Water pressure/bar | 0 | 0 | 1.8 | 1.8 | 1.6 | 1.7 | 2.5 | 2.6 | 2.4 | 2.4 |
| Amount of peristalsis pump water applied/kg.h⁻¹ | 0 | 6 | 15 | 21 | 30 |
| On-line instrument steam dryness/% | 100 | 98 | 98.3 | 91.2 | 93 | 86 | 86 | 82 | 81 |
| Off-line instrument steam dryness/% | 119 | 117 | 98 | 99.4 | 91 | 93 | 87 | 86 | 81 | 82 |

Note: Numbers above 1 are based on 1.

The above recorded data are summarized as the influence of water addition on dryness as shown in Table 4.

| /kg.h⁻¹ | 0 | 6 | 15 | 21 | 30 |
|----------|---|---|---|---|---|
| On-line instrument steam dryness/% | 100 | 98 | 91.97 | 86.05 | 81.73 |
| Off-line instrument steam dryness/% | 118.2 | 98.81 | 92.24 | 86.05 | 81.55 |
7. Conclusions
The fitting curves of off-line and on-line steam dryness test results are basically coincident. Within the explored dryness range (Note: the measurement range of on-line steam dryness tester is 30% - 100%, which is 100% when it is over 100%), the data change trend of on-line and off-line dryness tester is the same. It can be seen that the on-line dryness tester developed in this project measures the dryness of steam is reliable and accurate.

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