

# 基于单片机控制的气流换向干燥系统研究

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**摘要:** 为提高干燥品质、减轻劳动强度和实现干燥过程自动化, 研制了基于单片机控制的气流换向干燥系统。采用“小参数热风渗流、间接加热、气流换向深层干燥”的干燥工艺, 对系统的性能进行了试验研究和分析, 同时, 对气流换向及气流内循环在干燥中的作用和效果进行了讨论。结果表明, 气流换向干燥系统和所采用的干燥工艺能有效地保证干燥物料, 特别是粮食种子的质量指标。

**关键词:** 气流换向; 干燥; 单片机; 控制; 气流内循环

**中图分类号:** TP368 1; TP273 5; S375

**文献标识码:** A

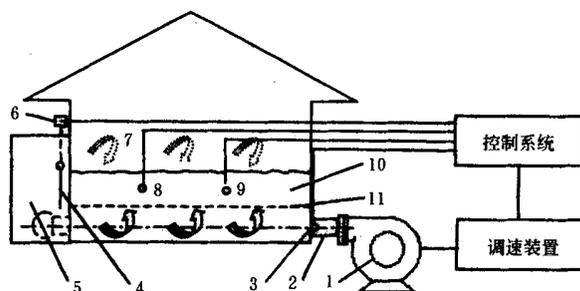
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根据干燥工艺参数(如干燥时间、物料的温度等)改变热空气进入干燥室内方向的气流换向干燥工艺可均衡干燥室内的温度场, 提高物料的干燥品质, 因而应用广泛。但传统的热空气方向的切换方式采用人工操作, 无法实行精确控制, 为此研制了基于单片机控制的气流换向干燥系统。

## 1 干燥系统组成和工艺流程

### 1.1 干燥系统组成和工作原理

气流换向干燥系统组成如图 1 所示。风机 1 将空气经风道 2 进入燃烧室 5, 燃料(煤或秸秆)燃烧加热, 经换热器换热后变成热空气, 送至气流换向闸门(简称闸门)4 处。干燥室进风口和物料层内布置有多个温度传感器 8, 用以测量进风温度和物料层内部的温度。理论上, 料温应测量物料籽粒内部的温度, 但这在实际生产中不易测试, 另一方面, 籽粒内部温度与物料层内部的温度间具有确定的关系, 该关系可由试验确定, 因此, 可以通过控制物料层内部的温度来间接控制料温。控制系统根据温度传感器所测得的温度通过干燥进程时间控制继电器控制闸门操纵机构动作, 来改变闸门开启的方向, 以决定热空气是进入干燥室的上部(对应虚线弧箭头), 还是进入干燥室的下部(对应实线弧箭头), 穿透被置于多孔板 11 上, 待干燥物料 10 热空气从上方或下方穿透通过对物料进行干燥。湿度传感器 9(多点)在干燥过程中起监测作用, 调速装置用来改变风机的转速, 从而改变进风量的大小, 进风量的大小由压差传感器 3 测得。



- 1 电机及风机
- 2 风道
- 3 压差传感器
- 4 气流换向闸门及其操纵机构
- 5 燃烧室
- 6 继电器
- 7 干燥室
- 8 温度传感器
- 9 湿度传感器
- 10 物料层
- 11 多孔板

图 1 气流换向干燥系统简图

Fig 1 Schematic diagram of direction-change air-flow type drying system

### 1.2 气流换向干燥工艺流程

影响物料干燥品质的主要因素是热风温度、物料受热时间和风量比。为了有效地保证物料干燥质量, 采用“小参数热风渗流、间接加热、气流换向深层干燥”的干燥工艺, 并可进行气流内外循环的操作工艺。对于种粮干燥, 其主要设计技术参数取: 谷床面积为  $40 \text{ m}^2$ ; 干燥速率为  $(0.5\% \sim 0.6\%) / \text{h}$ ; 风量比, 即每秒渗流通过  $100 \text{ kg}$  种粮的风量为  $0.04 \text{ m}^3$ ;  $1 \text{ kg}$  水的单位热耗为  $8000 \sim 8500 \text{ kJ}$  (由于采用间接加热, 且瓦管换热的效率较低, 所以单位热耗取得较高); 平均生产率为  $0.75 \text{ t/h}$ 。生产实践证明, 这一干燥工艺能保证种子干燥后发芽率不降低、爆腰率不增加。

气流换向干燥的工艺流程如图 2 所示。燃烧室 5 燃料燃烧产生的热能加热了燃烧室上方的换热器 4, 高温烟气从换热器铸铁管外部经过, 由燃烧室后壁出口至沉降室, 然后进入瓦管 11, 再经瓦管流向烟囱 10 排出。风机 13 所吹送的空气流经瓦管外部,

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与瓦管内的烟气流进行热交换, 形成预热(空)气, 再进入换热器内, 由燃烧室进一步加热, 形成热空气。热空气经气流换向闸门 2 进入干燥室的上部或下部, 渗流透过物料层, 加热物料, 物料内部水分外移

被蒸发带走。含有大量水分的湿空气从干燥室下排气窗口 8 或上排气窗口 1 和通道排出。根据干燥工艺的需要, 也可将通道的排气门 12 关闭, 使废气经通道进入风机, 进行再循环(内循环)。

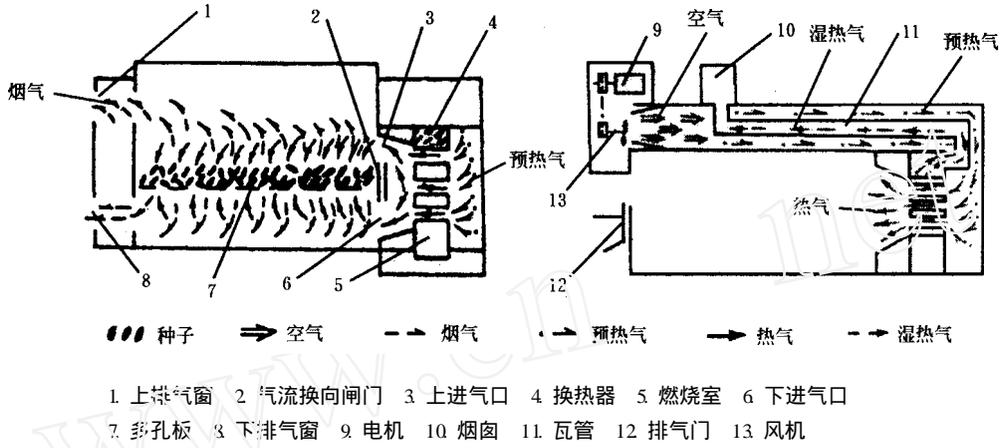


图 2 气流换向干燥工艺流程示意图

Fig 2 Diagram of the technological process

## 2 控制系统设计

### 2.1 控制系统硬件设计

控制系统的硬件组成如图 3 所示。80C196KC 单片机为主控单元, 外部扩展是程序存储器 (EPROM) 和数据存储器 (RAM)。系统采用模块化设计, 便于修改和扩充, 各功能模块挂在总线上。为了保存数据, 通过单片机的串行通信口外接 PC 机。

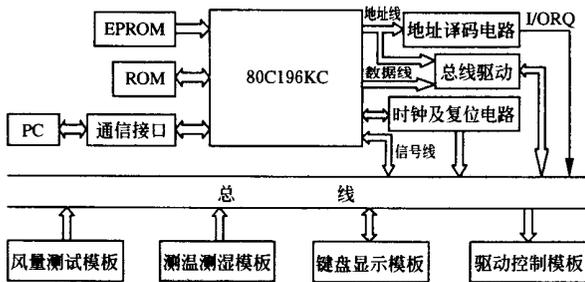


图 3 控制系统硬件组成框图

Fig 3 Function frame of the control system

系统的控制参数为风温、风量和料温(用物料层内部的温度表示, 下同), 受控参数为风机转速和气流换向闸门开启方向。风量测试模板测量进入干燥室的热空气量, 测温测湿模板测取干燥室内的温度(多点)和湿度(多点)。被测模拟量经过变送器变换成为 0~ + 5V 范围内变化的直流信号, 经单片机内的 A/D 转换器变换后, 供数据处理程序调用; 其它型式的被测参量也作相应处理。数据处理程序依据相应的控制算法求出控制量的大小, 经单片机的 PWM/P2.5 引脚输出一电压信号, 送往驱动控制模

板; 由单片机输出的开关量控制信号经锁存后, 也送往驱动控制模板。驱动控制模板控制风机调速装置和气流换向闸门继电器, 以此来调节进入干燥室的风量和气流换向闸门的开启方向。同时, 实现与 PC 机间的实时通信。

键盘显示模板是通过 8279 接口芯片连接的, 具有 8 个 8 位数码显示和 20 个按键。其主要功能是实现控制参数的在线输入与调整以及对系统的运行状态进行监测, 包括系统正常运行时的显示和出现异常情况时的报警等。

### 2.2 控制系统软件设计

控制系统软件采用模块化程序设计方法设计, 在保证系统功能的前提下, 重点考虑软件的抗干扰能力和系统资源的合理分配。系统软件主要包括: 1) 主程序: 系统初始化, 键盘管理和显示; 2) 数据采集子程序: 数据采集, A/D 转换; 3) 数据处理及输出控制子程序: 频率计算, 数字滤波, 控制逻辑处理及控制输出; 4) 串行通信子程序: 完成与 PC 机之间的实时通信。

## 3 性能试验与结果分析

气流换向干燥系统性能试验的测定结果如表 1, 试验材料: 籼稻, 品种为原红早; 小麦为混杂麦。进风温度为 50, 风量为 6 m<sup>3</sup>/s

以水稻为例, 试验的主要性能指标: 干燥速率为 0.61%; 蒸发 1 kg 水分的单位热耗量为 8.840 kJ; 平均小时生产率为 0.61 t。引起热耗增加和生产率下降的原因是: 1) 采用间接加热方式; 2) 物料实际原始

表 1 气流换向干燥系统性能试验测定表

Table 1 Measured results of performance test

物料种类	环境温度 /	环境相对湿度/%	物料条件							发芽率/%		爆腰率增值/粒
			物料质量/t	料厚 /cm	干前含水率/%	干后含水率/%	进料温度 /	热料温度 /	出料温度 /	干燥前	干燥后	
稻	29	89	7.02	30	23.6	13.69	29	43	35	91.5	92.5	-2
麦	26.7	78	3.07	10	17.8	12.45	25	40	30	95.5	99	0

含水率比设计值高; 3) 本试验为新建干燥室的首次试验, 测定的其余各项性能指标均达到或超过了设计值, 种子的发芽率和爆腰率值均比日晒者好。

图 4 为各层物料含水率随干燥时间变化的关系。上层物料的干燥速率最快, 这是因为表层物料的自由表面大, 水分易于蒸发; 中层物料在前 6 h 一直缓慢下降, 进入等速干燥后才转入下降; 而下层物料直接铺放在多孔铁板上, 受热温度稍高, 其干燥速率也高于中层。由于采用了气流换向工艺, 使得干燥带上下交替不断向中间移动, 直至降到各层物料含水率符合要求为止。从图中还可以看出, 在初始阶段(尚未换向)上下层的含水率均低于中层, 这是因为: 1) 所采用的干燥工艺, 干燥过程较缓慢; 2) 下层物料首先与热空气接触, 而上层物料的表面积大, 加之物料原始含水率高, 水分易于挥发。

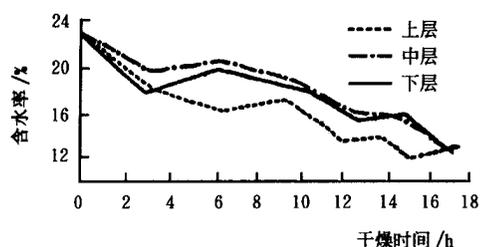


图 4 物料含水率与干燥时间的关系

Fig. 4 The relationship between grain moisture content and drying time

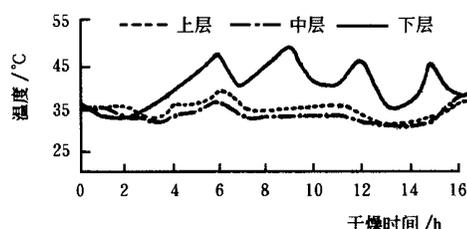


图 5 物料温度与干燥时间的关系

Fig. 5 The relationship between grain temperature and drying time

干燥过程各层物料温度与干燥时间的关系示于图 5。各层物料受热温度为下层稍高, 上层次之, 中层稍低。从图 4 和图 5 可见, 上下两层的物料含水率和受热温度都是交替的降低、升高、降低、升高

……直至达到所需要的控制范围。这种梯度效应现象的产生, 正是气流换向的结果。它使上下两层物料在直接接触热风时, 由于热风温度高, 蒸发速度快, 水分向下或向上移动, 使得干燥和缓苏交替发生, 而保证种子发芽率和爆腰率符合品质要求。

因下层物料铺放在多孔铁板上, 温度易于上升, 在干燥时以其温度不超过 43 (水稻) 为基准, 一旦超过此值就换向, 物料温度就会降低。然而, 由于热惯性的作用, 尽管气流换了向, 但下层物料温度却不能随之立即降低, 而是继续上升一些才下降, 有的点甚至高达 48。不过, 由于受热时间短, 加之气流换向后下层物料所受热风湿度大, 故不会影响种子的发芽率和爆腰率。为防止因热惯性而频繁换向, 在控制软件上采用适当的方法, 使得在每次换向后的一定时间(该时间随干燥进程而改变)内, 能维持现状而不会换向。生产过程中, 定时(每次换向后)测量物料的含水率, 当其满足要求时, 即可停机。

#### 4 气流内循环在干燥中的作用

种子、商品粮以及其他农副产品的干燥都是通过控制温度、湿度的变化来保证干燥质量。控制气流内循环是控制温度、湿度的重要手段之一。物料干燥的水分转移规律可用下式表示

$$i = - \partial r^0 \left( \frac{\partial u}{\partial x} + \delta \frac{\partial t}{\partial x} \right)$$

式中  $i$ ——水流量或水分密度;  $\partial$ ——水分转移系数或导水率;  $r^0$ ——物料纯干容重;  $\frac{\partial u}{\partial x}$ ——含水率梯度;  $\frac{\partial t}{\partial x}$ ——温度梯度;  $\delta$ ——热湿传导系数或热梯度系数。

若视干燥物料为杆状吸湿性物体与周围介质不发生湿交换, 由上式可知, 如其内部造成某种温度梯度, 水分将向温度低的一侧移动。结果低温部分的含水率升高, 高温部分的含水率降低, 在物体内部形成含水率梯度。在含水率梯度的作用下, 水分将与最初移动的方向作相反的移动, 当温度梯度与含水率梯度达到一定关系时, 湿热传导的效应完全为水分传导的效应所抵偿, 在杆状物体内部形成稳定的温度场和含水率场。要想达到这一预想的效果, 干燥设备

应具有气流内循环功能。为使被烘干物料内水分的温度从中心到表面均匀地提高到一定程度, 就必须在空气介质对物料加温的同时, 使介质的湿含量增加, 只有在这样的条件下, 经过预热后才能使物料的温度梯度和含水率梯度一致。气流内循环能保持含湿量高的废气不外溢, 增加了空气中水蒸气的分压, 也就阻碍了物料在预热段与外界进行湿交换, 有利于物料湿度的内外平衡, 使温度梯度与含水率梯度一致。另外, 还可以利用废气再循环原理对物料进行温湿度的调节, 以保证干燥品质。从图 5 可知, 在水稻干燥中, 前 3 h 采用了废气再循环, 而后再根据不同的干燥阶段将气流换向和气流内循环交替使用, 有效地保证了种子的质量指标。

## 5 结 论

1) 采用“小参数热风渗流、间接加热、气流换向深层干燥”的干燥工艺, 有效地保证了干燥品质。特别对于保证种粮干燥后发芽率不降低、爆腰率不增加, 而且没有污染。

2) 进气空气流与排气烟气流进行热交换, 形成预热气, 再经换热器进一步加热, 形成热空气, 提高了热量的利用率。

3) 利用废气再循环原理可以使被干物料内部的温湿度梯度一致, 有利于干燥过程的顺利进行。

4) 控制系统总体结构合理, 运行可靠, 在线调试方便, 易于实现干燥规范的操作; 软、硬件设计均实现模块化, 结构紧凑, 便于进一步扩展, 使用维护方便; 具有一定的通用性, 较易移植到其它类型干燥设备的自动控制中。

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**Abstract:** The extraction of the flavonoid from Pagodatree flower with water system and alcohol-water backwatering system was studied. With water extracting method, the effect of temperature, pH value, and different technology was studied. With alcohol extracting method, through the orthogonal experiment, the optimum technical condition is obtained. The results showed that the optimum technology of extracting flavonoid from the Pagodatree flowers is B2C3A2, namely, 2 times volume 40% alcohol-water, 3 extracting times (2 h/each time), and the content of flavonoid is 13.04%.

**Key words:** pagodatree flowers; optimum technical conditions for extraction; backwatering; orthogonal experiment; flavonoid

## · Agricultural Electronics and Information Technology ·

### **Information Processing System for Precision Agriculture Based on GPS and GIS ... (145)**

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**Abstract:** To acquire spatial information quickly and analyze it properly, an information processing system which uses MapObjects to integrate GPS with GIS is researched. This information processing system has the function of visualizing and analyzing spatial data, showing and tracking moving point and calculating area of closed polygon. It can integrate GPS and GIS into Expert System and Decision Support System perfectly. A new way of information processing and a new model of information processing system for the research of precision agriculture are put forward.

**Key words:** precision agriculture; GIS; GPS; information processing system

### **Fuzzy Pattern Recognition Method Based on Image Contour Line ..... (150)**

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**Abstract:** A simplified method was put forward on a binary image contour line extraction. Distance between centroid and dots on contour line was calculated, and based on the maximum centroid-dot distance, a feature vector including twelve direction segments and lengths of contour line was studied in this paper, and two distance algorithms based on euclid distance were promoted. The experimental results show that the correct recognition ratios on three kinds of paddy seed reach respectively 79.89%, 89.63% and 93.27%. This method can also be applied to fuzzy pattern recognition on fruits, machine parts etc. As random of object's lay direction and side were taken into account in this paper, and objects are recognized at the same direction and on the same side, so this method can also be promoted to the optic measurements on object rotation angle and any preindicated geometrical parameters.

**Key words:** paddy seed; image; contour line; fuzzy pattern recognition

### **Measuring Area of Leaves Based on Computer Vision Technology by Reference Object ..... (154)**

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**Abstract:** A method of measuring area of leaves by reference object based on computer vision technology was studied. The sampling box of live leaves was developed, and its data were optimized. The measurement process was studied. The reference object was segmented from the original image by the method of threshold. The data of threshold was gained by means of derivation. The way of removing the noises in the image was studied. Generally, the results show that this method has better feasibility, higher precision and higher efficiency.

**Key words:** leaf area; computer vision; method of reference object; measurement

### **Reversible Airflow Drying System Based on Single-Chip Computer Control ..... (158)**

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**Abstract:** In order to improve drying quality, reduce manpower intensity and realize automatic drying, a reversible airflow drying system based on single-chip computer control was developed. Utilizing the technological process, "reversible airflow and deep bed drying indirectly", the performance experiments and analyses of the system were carried out. The function and effect of the inverse air current and the inner-outer air current cycle in the drying process were discussed. By using the system and the technological process, the qualities of the dried materials, seeds especially, can be ensured effectively.

**Key words:** reversible airflow; drying; single-chip computer; control; inner air circulation

### **Fuzzy Control System for Grain Dryer** ..... (162)

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**Abstract:** The fuzzy control algorithm was applied to the automatic control system for controlling the outlet grain moisture content of grain dryer. The intelligent fuzzy controller was developed on the basis of 89c51 single-chip computer. The method for designing the hardware and software of the control system was also studied. The results for online control of the wheat moisture content in the grain dryer show that the high precision and real time control can be realized using this system.

**Key words:** fuzzy control; single-chip computer; grain dryer

## **· Land Consolidation and Rehabilitation Engineering ·**

### **Research Advances of Gradation and Evaluation of Agricultural Land in China** ..... (165)

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**Abstract:** The research development of recent agricultural land evaluation in China was reviewed. The two method systems, ideological bases and practical significance raised respectively in newly-formulated National Rules of Classification and Gradation of Agricultural Land and Rules of Soil Fertility Gradation of Cultivated Land were analyzed and compared. The classification and gradation evaluation of agricultural land developed from such low-level researches on natural soil condition investigation for estimating yield, soil nature and basic soil fertility, etc. to management and evaluation of resource value integrated with land and human being. The existing two evaluation methods of agricultural land in China are the gradation system of soil fertility of cultivated land formulated by Ministry of Agriculture and the classification and gradation evaluation system of agricultural land drafted by Ministry of Land and Resources. There exist differences between the two systems in analyses of evaluation indexes, objective levels of achievement application and links of front and back operation. Currently, the classification and gradation evaluation of agricultural land have been implemented across China, whose method system perfection is of great practical significance.

**Key words:** agricultural land; gradation and evaluation; advance

### **Dimension Design of Farmland and Application of GPS-GIS-RS Technology to**

### **Land Consolidation** ..... (169)

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**Abstract:** The paper established and quantitatively analyzed the model of dimension design of farmland, applying Integral Plan. It also put forward the ways of applying GPS-GIS-RS technology to land consolidation. The model and the ways were based upon the example of Taoyuan Project Land Consolidation in Pingyang County.

**Key words:** land consolidation; dimension design of farmland; GPS-GIS-RS technology