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DRYING WOOL AND OTHER DIRECT USES OF GEOTHERMAL ENERGY IN HEBEI, CHINA

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ABSTRACT

Geothermal well Gao4, at 3432 m depth, a wellhead temperature of 114°C, shut-in well pressure of 1.5 MPa, and artesian flow of 2160 m^3/d, has the highest well temperature in Northern China. Located in Gaoyang County, Hebei Province, it has been used for drying wool because of the many wool mills near Gaoyang County. The drying equipment is a geothermal net conveyor belt drier. The moisture content by wet basis of the moist wool is 40% and the moisture content by wet basis of the dry wool is 15%; the dry wool product capacity is 280 kg/h, the dehydrating capacity is 120 kg/h and the temperature of the hot air can reach about 95ºC. The residual water leaving the geothermal drier is also used in geothermal greenhouses (7337 m^2), district heating (1500 m^2), fish ponds (3335 m^2) and geothermal bathing. Multiple use of geothermal energy is a reality in Gaoyang County.

1. INTRODUCTION

The main characteristics of the geothermal resources in Hebei Province are their abundance and presence in so many places. The known areal extent of the geothermal resources is 9420 km^2, the exploitable quantity is 8.36×10^{16} kJ. There are 253 discovered geothermal wells and hot springs in the Province; in 19 of these the temperature is over 80ºC, in 33 it is between 60 and 80º, and in 30 it is between 40 and 60 ºC.
The total reserves of geothermal resources in Hebei Province are the third largest in China, and its reserves of medium and low temperature resources are the largest in China.

So far, 31 cities and counties in Hebei have developed and utilized their geothermal resources, in greenhouse heating (vegetables and flowers), fish farms, district heating, convalescence homes and in drying processes.

Following a study of market demand near Gaoyang County, multiple geothermal uses have been developed, with drying as the main application, utilizing the fluids of geothermal well Gao 4. The results have been excellent and have also achieved energy savings.

2. GEOTHERMAL WELL GAO 4 AND THE CASCADE USES OF THE RESOURCE

The geothermal well Gao 4 is located 9 km west of the town of Gaoyang, about 160 km south of Beijing. Its depth is 3432 m, and its wellhead temperature is 114ºC, the highest well temperature in Northern China; shut-in well pressure is 1.5 MPa and artesian flow is 2160m^3/day. Because the wellhead temperature is rather high, hot air of more than 85ºC can be obtained by heat exchanger and used for drying. As there are many wool mills near Gaoyang County, wool drying is the most feasible economic use of the resource. The residual water leaving the geothermal drier is also used for other direct geothermal utilizations.

On the basis of their various temperature requirements, the geothermal cascade utilization is as follows: geothermal well (114°C), geothermal drier (100°C), geothermal greenhouse and district heating (50°C), fish farms and bathing (35°C).

3. GEOTHERMAL ENERGY IN WOOL DRYING

3.1 The Geothermal Drier

The wool-drying equipment consists of a geothermal net conveyor belt drier. The length and width of the drying area are 10m and 1.2 m, respectively, which is separated into five drying units along its length. The wool on the net conveyor belt passes through the drying area from the first unit to the fifth unit by way of the conveyor belt from a stepless speed change motor. Depending on the characteristics of the drying wool, we use either inlet air, circulated air or exhaust air for each drying unit. In the fifth unit, the inlet air is fresh air from the environment, and the exhaust air is forced to the first and the second units, as the inlet air for these two units. The exhaust air of the first unit is entirely discharged to the environment, while the exhaust air of the second unit is either entirely discharged to the environment, or partly discharged and partly used as circulated air. For the third and the fourth units, the inlet air is a mixture of 35% fresh air and 65% circulated air, and 35% of the exhausted air is discharged in the environment. The temperature of the inlet air is raised to the drying temperature by means of a heat exchanger.

The geothermal net conveyor belt drier is as shown in Figure 1, where 1 is the wool feeder, 2 the net conveyor, 3 the heat exchanger, 4 the air blower, 5 the circulation blower, and 6 the moisture exhaust blower.

3.2 Heating Calculation of the Geothermal Conveyor Belt Drier

<u>The known parameters in the heating calculation</u>

Product capacity of dry wool (Wp) is 280 kg/h, the moisture content by wet basis of moist wool (ω_1) is 40%, the moisture content by wet basis of dry wool (ω_2) is 15%, the specific heat of dry wool (C_s) is 1.26 kJ/kg·ºC, the environment temperature(t_0) is 15 ºC, the absolute air humidity (d_0) is 0.0078 kgH_2O/kg dry air, the corresponding air enthalpy (i_0) is 34.72 kJ/kg, the drying temperature (t_1) is 70ºC in the fifth unit, and 90ºC in the other units.

<u>The heating calculation equations</u>

Jingshan Tong (1996) proposed the heating calculation equations of convection drying; we adopt these equations, integrating the geothermal parameters.

The main calculations are as follows:
Dehydration quantity is expressed as W(kg/h), so that:
$W=Wp(\omega_1-\omega_2)/(1-\omega_1)$ (1)

The quantity of heat for evaporating water is expressed as Q_1(kJ/h),so that:

$Q_1=W(2491+1.884t_2-4.186\theta_1)$ (2)
where t_2 is the exhaust air temperature, and θ_1 is the initial temperature of moist wool.

The quantity of heat for heating wool is expressed as Q_2(kJ/h), so that:

$Q_2=W_p(C_s(1-\omega_2)+4.186\omega_2)\cdot(\theta_2-\theta_1)$ (3)
where θ_2 is the final temperature of dry wool.

Heat losses of the drier are expressed as Q_3(kJ/h), so that:

$Q_3=(0.10\sim0.15)\cdot(Q_1+Q_2)$ (4)

Consumption of the drying medium is expressed as L(kg/h), so that:

$L=(Q_1+Q_2+Q_3)/(i_1-i'_2)$ (5)
where i_1 is the enthalpy of heated air at a temperature 1 and absolute humidity d_0, i'_2 is the enthalpy of heated air at temperature t_2 and absolute humidity d_0.

The total quantity of heat for drying wool is expressed as Q(kJ/h), so that:

$Q=L(i_1-i_0)$ (6)

Absolute humidity of the exhaust air is expressed as d_2(kg H_2O/kg dry air), so that:

$d_2=d_0+W/L$ (7)

The quantity of heat supplied by the heat exchanger is expressed as Q_t(kJ/h), so that:

$Q_t=Q/\eta$ (8)
where η is the heat efficiency of the heat exchanger, and 0.96~0.98.

The quantity of geothermal water flow is expressed as G(kg/h), so that:

$G=Q_t/[1.486(t_{w1}]-t_{w2})]$ (9)
where t_{w1} and t_{w2} are the temperatures of the geothermal water flowing in and out of the heat exchanger, respectively.

3.3 Design Parameters in Comparison with Measured Data

The geothermal net conveyor belt drier has been operating for 4 years, and has been modified and optimised 3 times after encountering operating problems. We made performance measurements in October 1998, and the design parameters and measured data are listed in Table 1. This Table shows that the measured data basically correspond to the design parameters.

The operating heat efficiency of the drier was a little higher than the design heat efficiency because the operating environment temperature was higher than the design temperature.

4. OTHER DIRECT USES OF GEOTHERMAL ENERGY AND ANALYSIS OF ENERGY SAVINGS

The other direct uses of geothermal well Gao 4, besides geothermal drying, are:

4.1 Raw Wool Washing

The grease and dirt in raw wool has to be washed with hot water at 50ºC . We adopt a heat exchanger and add some cold water to the geothermal water so that the hot water of 50ºC can be obtained directly and indirectly, and a lot of heat energy is saved.

4.2 Heating for Greenhouses and Buildings

The temperature of the residual water leaving the geothermal drier is still over 95ºC, so it can be used for heating greenhouses and buildings. Geothermal greenhouses of 7337 m^2 have been built around well Gao 4, and cucumber and tomatoes are planted there in the winter. Office rooms and living quarters of 15,000 m^2 are heated with geothermal water in the winter.

4.3 Using the Spent Geothermal Water

Part of the geothermal water after space heating flows to fish ponds of 3335 m^2; the rest is used for bathing.

4.4 Analysis of Energy Savings

Because geothermal water is used for washing and drying wool, for heating greenhouses and buildings, conventional energy is saved. Assuming that the boiler heat efficiency is 65%, the analysis of energy savings is as shown in Table 2.

5. CONCLUSION

Geothermal drying uses the high enthalpy of medium and low temperature geothermal resources, so that the multiple utilization with geothermal drying as its main part not only makes the various utilizations coordinated and rational, but also provides economic benefits and energy savings. Because of the rather high temperatures of the geothermal resource of well Gao 4, the geothermal net conveyor belt drier makes a success of drying wool, and it is the geothermal drying equipment with the highest drying temperature in China.

REFERENCE

Jingshan Tong (1996). Fluidized Drying Technique and Equipment, China Construction Press, Bejijng, pp. 21-25.

Table 1. Design parameters compared with measured data

Comparison parameters	Design parameters					Measured data				
	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5
Quantity of air (kg/h)	3328	2030	2792	2792	5358	3214	2240	2710	2743	5510
Drying temperature (ºC)	90	90	90	90	70	90	92	94	93	72
Environment temperature(ºC)	15					18				
Environment relative humidity (%)	70					68				
Moisture content of moist wool (%)	40					42				
Moisture content of dry wool (%)	15					16				
Dehydrating capacity (kg/h)	120					123				
Product capacity of dry wool (kg/h)	280					275				
Quantity of geothermal water flow (kg/h)	36300					36500				
Heat efficiency of drier (%)	44.2					46.3				

Table 2. Analysis of energy savings

Content	Annual energy savings (kJ/yr)	Conversion into standard coal (t/yr)
Geothermal washing wool	2.57×10^9	135
Geothermal drying wool	4.80×10^9	252
Geothermal heating	8.12×10^9	426
Geothermal greenhouses	5.30×10^9	278
Total	20.79×10^9	1091

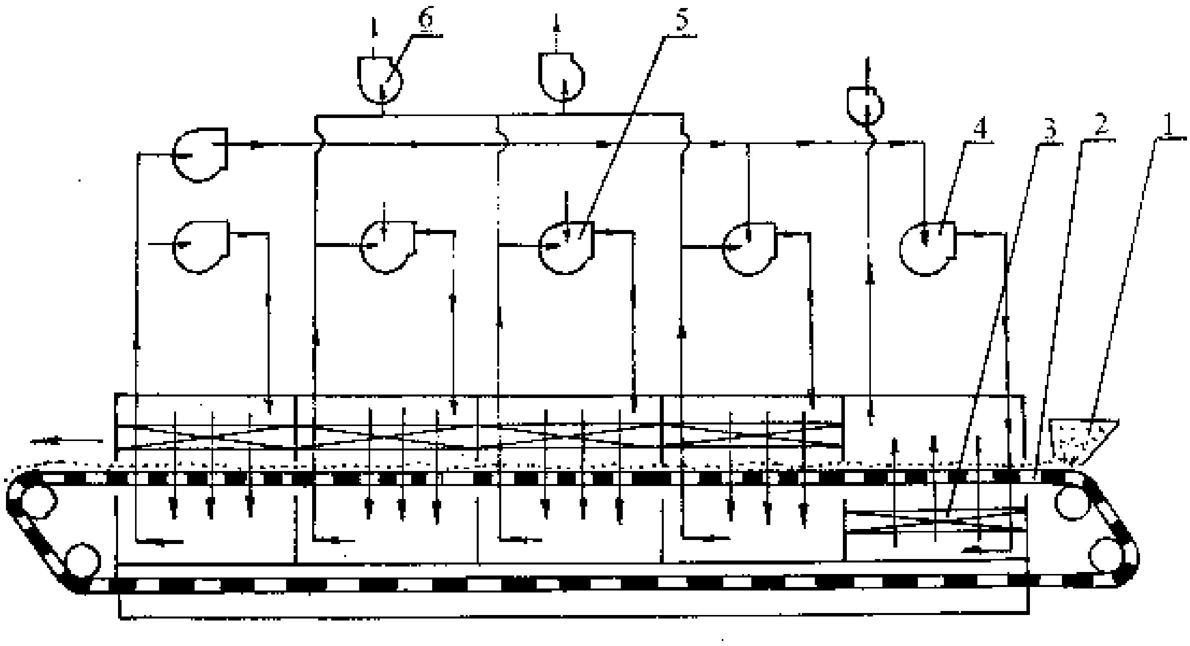

Figure 1. Design of geothermal conveyor belt net drier