RESEARCHING ON BURNER, CONSTRUCTING EQUATION OF AIR FLOW VELOCITY AND DEFINING APPROPRIATE DRYER WALL FOR TOBACCO DRYER IN VIETNAM

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SUMMARY

In this report, we perform researchs of heat transfers which mainly are burner, velocity equation of natural convectional air-flow in dryer chamber, and dryer wall.

Burner: the purpose is to control temperature in drying process, decreases fuel cost, increases uniform of temperature in the dryer chamber to enhance the quality of dried tobacco as well as prevent fire.

Model of burner in research is made of 2 layers of steel with air between, 2 pipes for air in and 4 ones for hot air out.

Equation of air-flow speed : The amount of air coming to the dryer chamber influences much to moist existence of tobacco leaf, and quality of tobacco leaf after drying. The amount of coming air depends on area of inlet and moist outlet, height of inlet and outlet, obstacle/resistance of tobacco in chamber, and temperature difference between chamber and surroundings. We had established natural convection air-flow speed through tobacco layer.

Wall of dryer : Wall of dryer is an important part of the process of drying agricultural product in general and tobacco leaf in particular, creates space to maintain dry regulation for dry process. It prevents losing of temperature to surroundings through the wall.

By calculating the amount of heat that lost through the wall, analyzing economic effects, using brick wall for 5x6 m^2 tobacco leaf dryer is the most economic effectiveness for 10-14 dry batches in year.

I. RESEARCH OF DESIGNING BURNER

With purpose of controlling the temperature for dry process, decreasing cost of fuel, increasing uniform of temperature in the dryer chamber to enhance the quality of dried tobacco leaf and prevent fire, new model of burner is researched as follows :

To repair the disadvantage of brick burner, it is necessary to research the model of steel burner. Because steel has many features : not crack in long dry process so that prevents causing fire; coefficient of heat-conductibility of steel is high so that the amount of heat which spreads around the chamber is high, this fact is suitable to the burner of tobacco leaf dryer, because it is located in the dryer, so its additional function is a heat - transfer part.

Because of high amount of heat spreading and gathering around burner, researching of new model of burner makes sure that this high amount of heat is distributed equally in space of dryer.

Therefore, it is necessary to research of designing a layer of steel enclosing burner, and makes an empty space between two layers to keep the air; designing 2 pipes for air coming to the empty space and 4 pipes to lead the air which takes heat of middle layer to corners of dryer. To make a natural convection, the inlet and outlet pipes are separated by the height, and the inlet pipes are under the others.

To adjust the amount of air coming to dryer that meets requirements of dry process, design a lid to adjust amount of coming air at the beginning of inlet pipe.

Therefore, the model of burner in research is made of 2 steel layers with empty space in between to keep the air, and 2 inlet pipes to lead air in and 4 outlet pipes for hot air coming out.

With the above model, here researching to design parts of burner, based on amount of maximum specific consuming fuel (B_{max})

Designing of burner includes dimensions of grate and volume of burner so that keeps all maximum amount of fuel and supplies enough amount of air that burns this amount of fuel.

1. Calculating of designing grate of burner :

Grate must provides enough air for fuel's burning process, correlative with maximum amount of consuming fuel $B_{max} = 6.10^{-3}$ kg/s

Area of grate surface is defined by :

$$F_g = \frac{B_{max} L_\alpha}{W_g Jk} \left[m^2\right]$$

with Bmax = 6.10^{-3} kg/s (as previous researches)

L_α : Amount of air providing for burning fuel (depends on type of fuel); with charcoal : $L_\alpha = 9.1826$ m^3/kg

J : area of activated grate: 30%

W : air speed through grate : 0,5 m/s

k : coefficient of consuming, with briquette in grate : k = 0,6

→ F_g= 0.612 m^2

Choose width of grate is 0.58m; length of grate is 1.08m

Area of grate : F_g = 0.58 x 1.08 = 0.626 m^2

2. Calculating to design volume of burner :

Define volume of burner so as to keep all maximum consuming fuel, and base on density of volume of this to calculate:

$$V_{bd} = \frac{Q_t^d B_{max}}{q} \left[m^3\right]$$

q : heat density of volume of chamber.

$q = (290 \div 232)\ W/m^3$ [5]

$Q^d_t = 18820.10^3$ [J/kg]

$B_{max} = 6.10^{-3}$ [kg/s]

$V_{bđ} = (0.389 \div 0.487)\ m^3$

Volume of designed burner is around

$$V_{bđ} = (0.389 \div 0.487)\ m^3 \quad (1)$$

Calculating dimensions of burner to satisfy condition (1).

Designed burner type is a horizontal cylinder, beveled bottom to place the grate, length of grate along to burner to save manufacture materials and burning flame easily directs to pipe, the cylinder part at the end of burner is joined with intermediary pipe by a truncated cone as Picture 1.

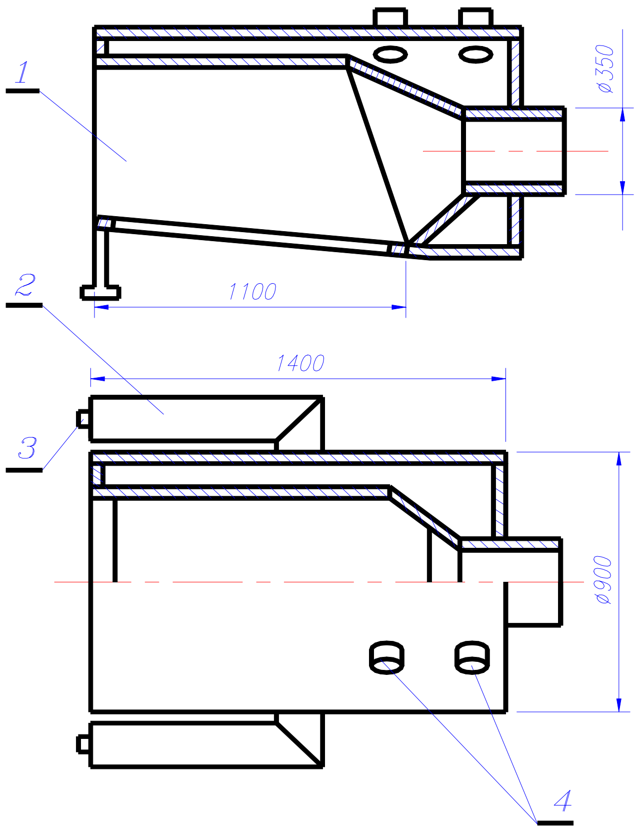
Area of beveled surface 0,6m x 1,1m, inside diameter of cylinder is 0,8m.

Volume of burner :

$$V_{bd} = \left(R^2 \pi \frac{360 - 2\alpha}{360} + R \frac{AB}{2} \cos\alpha \right) L_{tb} = 0.433$$

This volume is satisfied condition (1). Burner is at high temperature (950°C), so make a cover of CT_3 steel 2-3 mm thickness.

Therefore, the inside layer of burner (5 mm thickness) and the outside has an empty space, design more 2 pipes taking air in (2) under figure (4) and taking hot air out (4) at figure 1



Picture 1: Completed steel burner

1. *Burner*
2. *Inlet air pipe*
3. *Inlet air adjustment lid*
4. *Outlet air pipe*

Sub heat pipes (4&5) are led to corners of chamber which are at lower temperature than in the middle of chamber.

Sub heat pipes is located so as to the coming hot air helps contributing temperature in the chamber equally. Thus quality of dried tobacco leaf is uniform and higher.

The coming air to empty space takes heat by 2 pipes (2). Inlet air adjustment lid is at the top of pipe (3).

Step 1 : Temperature of chamber is 32^{o}C to 38 ^{o}C, adjustment lid (3) is closed. Because recent process of covering up tobacco leaf leaves needs high moisture to change color.

Step 2&3 : The temperature is 39-65^{o}C, adjustment lid (3) is opened to take air.

3. Setting sub heat pipes

Two inlet air pipes (2) at sides of chamber are 0,7m length, 150mm diameter, adjustment (3) is made of steel pipe CT_3, 0,8-1mm thickness.

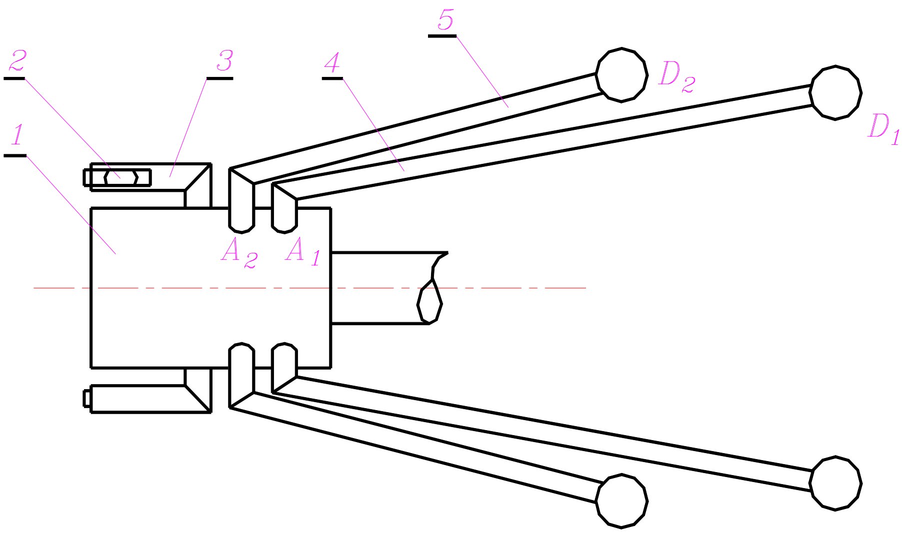
Outlet hot air (Picture 2) consists of 2 long pipes (4) and 2 short pipes (5), made of steel pipe CT_3, 0,8-1mm thickness, 130mm diameter.

Calculate A_1D_1 pipe : as Picture (2) :

$$A_1D_1 = 0.17 + 3.83 + 0.2 = 4.2 \text{ m}$$

Calculate short pipe A_2D_2 :

$$A_2D_2 = 0.17 + 2.42 + 0.2 = 2.8 \text{ m}$$



Picture 2: Setting sub heat pipes

1. Burner; 2. Air adjustmen lidt

3. Inlet air pipe; 4. Long outlet air pipe; 5. Short outlet air pipe

4. Amount of heat spreading around steel chamber :

Burner is designed as Picture 1. Chamber is located inside dryer, thus chamber is one of spreading heat sections of exchanging heat equipment.

$$Q_1^{'} = \frac{t_1 - t_{kk}}{\frac{\delta}{\lambda} + 0.06} F[W]$$

Amount of heat spreading around chamber is calculated as follow :

t_t : temperature of chamber wall. Temperature of burning fuel is 950^{o}C so

$t_t = 750^oC$

$t_{kk} = 27^oC$: temperature of outside air coming to the middle layer of chamber

Thickness : $\delta = 5.10^{-3}$ m ; $\lambda = 29.8$ W.m^{-1} .độ $^{-1}$

F = L.S [m^2]

L : length of chamber = 1,1m

S : inside vinculum of chamber = 2m

F = 2,2 m^2

Q'_1 = 26.436 W

With rather high temperature of surroundings chamber, design 4 pipes above to take amount of heat to 4 corners of chamber.

5. Amount of heat spreading around sustainable fire brick burner

Similar to above calculation, we calculated amount of heat spreading around fire-brick burner : $\delta = 0.2$m ; $\lambda = 0.77$ W.m^{-1} .độ $^{-1}$; t=430^0 C

Q_g = 2.773 [W]

6. Tested results

By researching and testing 2 types of burners (2 steel layers type and fire-brick type), 3 times for testing each type, in same conditions of structure of dryer chamber, tobacco leaf type, fuel type,... we got results of fuel cost in Table 1 :

Type of burner	Test No.	Amount of firewood (ster)	Amount of coal (kg)	Energy cost (kJ/kg dried tobacco leaf)
Fire sustainable brick	1	2.7	1774	98.193
	2	3.2	1805	103.933
	3	2.8	1769	98.872
	Average	2.9	1782.7	100.332
2 layers of steel	1	2.3	1580	86.523
	2	2.1	1687	89.220
	3	1.9	1766	90.747
	Average	2.1	1677.7	88.830

7. Conclusion

By calculating and testing 2 types of tobacco leaf burner, we concluded as follows :

Amount of heat spreading around 2 steel layers burner is higher than sustainable fire brick one; because of intensifying heat spreading in it, so temperature of smoke coming out of heat exchange section of 2 steel layers this burner is lower than fire-brick one. Thus cost of fuel is lower too.

Hot air flow through 4 heat pipes ($V=7,7.10^{-2}$ m^3/s) is taken to corners of dryer chamber and makes temperature of this chamber more uniform than other types of heat exchange sections. Thus quality of dried tobacco leaves gains high 1st grade and 2nd grade.

Like this, using 2 steel layers burner gets much economic effectiveness than fire-brick one.

II. RESEARCH OF ESTABLISHING EQUATION OF AIR FLOW SPEED

Amount of air coming to dryer chamber influences much to moist existence of tobacco leaves and quality of dried tobacco.
Amount of coming air depends on area of inlet and moist outlet, height of inlet and outlet, resistence of tobacco in chamber, and temperature difference between chamber and surroundings. We had established natural convection air-flow speed through tobacco layer.

1. Difference of inlet and outlet is defined as the equation

$$\Delta p = gH\rho_0.(\frac{T_0}{T_{kk_2}} - \frac{T_0}{T_{kk_1}}) \ [N/m^2]$$

g : gravity acceleration
$T^o=273^oK$
H : difference of height of inlet and outlet doors.
ρ_o : particular mass of air in standard condition
T_{kk1} : temperature of outside
T_{kk2} : temperature of coming out air
Δp : difference of pressure height

Sum of resistance in dryer chamber :
Resistance of air moving in dryer chamber depends on inlet, outlet door, tobacco leaves arrangement in this chamber, is defined as the equation :

$$\sum h_c = h_{cv} + h_{cr} + h_{ll} = \xi_v \frac{\rho_0 W_{v0}^2 T_{kv}}{2T_0} + \xi_r \frac{\rho_0 W_{r0}^2 T_{kr}}{2T_0} + \xi_l \frac{H_l \rho_0 W_{l0}^2 T_{kl}}{2T_0 d_{td}} \ [N/m^2]$$

ξ_v; ξ_r ; ξ_l :coefficients of obstruction of inlet, outlet door and tobacco layer
T_{kv} ; T_{kr} : temperature of air coming to inlet and coming out of outlet [^oK]
T_{kl} : temperature of air through tobacco layer
W_{vo} ; W_{ro} ; W_{lo} :Air flow speed into inlet, through tobacco, out of outlet
H_l : height of tobacco layer [m]
d_{td} : equivalent diameter in space of dryer chamber

2. Defining equation of air-flow speed

Balance equation of resistance of dryer chamber has form:

$$gH\rho_0.(\frac{T_0}{T_{kk_2}} - \frac{T_0}{T_{kk_1}}) = \xi_v \frac{\rho_0 W_{v0}^2 T_{kv}}{2T_0} + \xi_r \frac{\rho_0 W_{r0}^2 T_{kr}}{2T_0} + \xi_l \frac{H_1 \rho_0 W_{l0}^2 T_{kl}}{2T_0 d_{td}}$$

At standard condition, air flow coming inlet, through tobacco, out of outlet are same.

$F_v\ W_{vo} = F_l\ W_{lo} = F_r\ W_{r0}$

Area of inlet and outlet are same, thus $W_{vo} = W_{ro}$

Empty area of tobacco layer depends on dimensions of tobacco leaves, location of tobacco leaves on tobacco plant, tobacco variety, cultivating regulation, tobacco leaf sticks arrangement and dry process.

Table 2

Period (dry temperature ^{0}C)	Type of tobacco leaves		
	Primings + tip	Leaf	Cutters + lugs
40	7.25	5.00	6.14
50	8.16	6.44	7.12
65	11.38	7.52	8.49
Average	**8.93**	**6.32**	**7.25**

Average empty area is 7,5 m^2

$W_{vo} = 7.5\ W_{lo} = W_{ro}$

$$gH\rho_0.(\frac{T_0}{T_{kk_2}} - \frac{T_0}{T_{kk_1}}) = \frac{\rho_0 W_{l0}^2}{2T_0}(\xi_v 7{,}5^2 T_{kv} + \xi_r 7{,}5^2 T_{kr} + \xi_l \frac{H_1 T_{kl}}{d_{td}})$$

Equation of air flow speed through tobacco layer in natural convection dryer is built as follow :

$$W_{lo} = \sqrt{\frac{H.g\left(\frac{T_0}{T_{kk_2}} - \frac{T_0}{T_{kk_1}}\right)}{\frac{1}{2T_0}\left(\xi_v 7{,}5^2 T_{kv} + \xi_r 7{,}5^2 T_{kr} + \xi_l \frac{H_1 T_{kl}}{d_{td}}\right)}} \quad [n.m/s]$$

In above equation, H & H_1 are defined as follow :

Using experimental tracing out to define some parameters which effects to uniform of temperature of handicraft tobacco dryer which has 5x6 m^2 horizontal section. Research of natural convection drying only mentions real elements which effect directly to process of research; are controllable and measurable quantities : area of inlet and outlet, height from inlet to outlet, number of tobacco layers in dryer, number of inlets (outlets).

Outlet parameter : Y –Uniform of temperature in dryer.

Equation Y= f(X_1, X_2,X_3,X_4) is built in experimental basis.

Region of research.

X_1 – Area of inlet, ensures to provide enough amount of air into dryer. ...

X_2 – Height of outlet, ensures enough height that correlative to mass of tobacco : X_2min = 3,8m

and not over-height that makes cost of building high : X_2max = 4,6m

X_3- Number of tobacco layers in dryer, ensures to arrange all amount of 3,5 T fresh tobacco.

X_3min =3 layers, X_3max =7 layers

X_4- Number of doors, arranges equally on 4 walls, minimum X_4min=6 doors, not many that makes much resistence to come in door, maximum X_4max = 14 doors

Define of level and varying gap of test elements following planned experimental.

Test arrangement.

Test arrangement follows full random method, experimental plan is 2 level rotatory constant of Box, Hunter.

After rejecting refression which do not ensure reliability out of model, regression equation in real type is defined as follow :

$$Y_3 = -1917.29 + 193.52 X_1 + 820.83X_2 + 40.89X_3 + 16.69X_4 - 96.93X_1^2 - 97.46 X_2^2 - 4.03 X_3^2 - 0.82X_4^2$$

The function gets climax at :

$X_1 = 1$; $X_2 = 4.2$; $X_3 = 5$; $X_4 = 10$.

Thus, to get highest equability of temperature, area of inlets (outlets) is 1m^2, height from inlet to outlet is 4,2m, number of tobacco layers in dryer chamber are 5, number of inlets (outlets) are 10.

3. Conclusion

With H = 4,2m and number of tobacco layers are 5, calculated H_1=5x0,6 = 3m (layers are separated 0,6m).

Experimental formula to calculate speed through tobacco layers of 5x6m^2 dryer (3,5T/ batch)

$$W_{lo} = \sqrt{\frac{4{,}2.g\left(\frac{T_0}{T_{kk_2}} - \frac{T_0}{T_{kk_1}}\right)}{\frac{1}{2T_0}\left(\xi_\nu 7{,}5^2 T_{k\nu} + \xi_r 7{,}5^2 T_{kr} + \xi_l \frac{3T_{kl}}{d_{td}}\right)}} \quad [n.m/s]$$

This is equation of air speed through tobacco layers of 5x6m2 dryer (3,5T/batch)

III. RESEARCH OF USING WALL OF TOBACCO DRYER

Wall of dryer is an important part of the process of drying agricultural products in general and tobacco in particular. It protects drying material from rain and wind, supplies space to

maintain dry regulation for dry process. It prevents losing of temperature to surroundings through the wall.
Tobacco dryer has large area of walls (99 m^2), thus needs to carefully calculate amount of heat losing through walls , also economic effectiveness to take out a suitable types of wall.

Research method

1. Define amount of heat losing through each type of walls

Amount of heat losing through walls depends on following factors : area of wall, wall thickness, coefficient of heat-conducting, temperature of drying and temperature of environment.

- Area of dryer wall : 4.5 * (6+5) *2 = 99m^2
- Temperature of dryer : 32^oC up to 65 ^oC in 120 hours to 130 hours of drying.

Average temperature of drying :

$$Ts = \frac{1}{\sum \tau_1}(\tau_1 T_1 + \dots + \tau_1 T_1) = 54^oC$$

Temperature of environment : $t_{mt} = 27^oC$
Other factors such as wall thickness, coefficient of heat-conducting are calculated in specific.
Amount of heat through each type of wall :

- Clay and straw wall :

$$Qv= \frac{t_s - t_{mt}}{\frac{\delta}{\lambda} + 0,06} F \quad [\text{ W }]$$

t_s : average temperature of drying 54^oC
t_{mt} : temperature of environment 27^oC
F : total area of dryer wall 99m^2
0,06 : Obstruction of heat, when there's heat exchange with surroundings.
δ : thickness of wall 0,1m
λ : coefficient of heat-conducting of wall 0,4127 [W/m.^oC]
$Q_đ$ = 8.745,0 W
- Brick wall : Q_g = 6.527,0 W

Thickness of brick wall : δ = 0,1m; λ = 0,29[W/m.^oC]
- Fibrocement wall : Q_f = 34.208,5 W

Thickness of fibrocement wall : $\delta = 6.10^{-3}$m; λ = 0,384[W/m.^oC]
Steel sheet with rice husk buffering wall : Q_{tr} = 2.511,5 W
Thickness of steel sheet wall : $\delta_1 = 5.10^{-4}$m; thickness of rice husk : $\delta_{tr} = 5.10^{-2}$m
Coefficient of heat-conducting of steel sheet: λ_t = 45,45[W/m.^oC]
Coefficient of heat-conducting of rice husk: λ_{tr} = 0,0504[W/m.^oC]
2 layers carton wall : Q_c = 5.387,4 W
Thickness of carton wall : $\delta_1 = 2.10^{-3}$m

Thickness of air layer : $\delta_{kk} = 5.10^{-2}$m

Coefficient of heat-conducting of carton: $\lambda_{ct} = 0{,}232$[W/m.^{o}C]

Coefficient of heat-conducting of air: $\lambda_{kk} = 0{,}121$[W/m.^{o}C]

By calculating, we set up table of summary of amount of heat losing through each type of wall:

Table 3 : Amount of heat losing through walls

Type of dryer wall	Amount of heat [W]
Clay + straw	8740.5
Brick	6527.0
Fibrocement	34208.5
Steel sheet + rice husk	2511.5
2 layers of carton	5387.4

Following Table 3, amount of heat losing through fibrocement wall is highest and through steel sheet + rice husk wall is lowest. However, to evaluate economic effectiveness of each type of wall, we have to calculate value of each type of wall and time of using that type to take out the most suitable and economical type of wall.

2. Cost of each type of wall :

By calculating, we set up a table of comparison of building cost of types of dryer wall and cost of using for depreciation each year.

Table 4 : Cost of building walls

Type of dryer wall	Price (đ)	Time of using (year)	Depreciation + Interest rate (d/year)
Clay + straw wall	3,872,000	3	1,600,427
Brick wall	6,711,000	10	1,114,021
Fibrocement wall	1,157,600	6	1,457,299
Steel sheet + rice husk wall	14,292,700	5	3,887,614
2-layers carton	8,575,600	4	2,787,070

Following Table 4, depreciation cost of brick wall is lowest, depreciation cost of steel sheet+rice husk wall is highest. Comchambere Table 3 and Table 4 to compare economic effectiveness of each type of walls.

3. Comparison of economic effectiveness of each type of wall :

Cost of energy through each type of wall is calculated : each drying batch takes 120-130 hours, value of heat of coal dusk in bar is 18820 kJ/kg. Price of coal dust is 380 VND/kg

Table 5 : Cost of energy through wall of 14 dry batches

Type of wall	Fuel cost of 14 dry batches (VNĐ)
Clay + straw wall	1,156,302
Brick wall	863,478
Fibrocement wall	4,525,542
Steel sheet + rice husk wall	332,248
2-layers carton	712,712

With normal tobacco drying, there're 10-14 dry batches a year. Thus, calculating economic effectiveness of one type of wall a year is for 14 dry batches. From Table 3 & Table 5, total price of brick wall is lowest. To prove advantages and disadvantages of types of wall like above, we do tests to verify.

4. Testing:

By testing dryers which have different types of wall, we set up a table of summary of cost of fuel for testing dry batches :

Table 6: Cost of fuel of types of wall

Cost / **Type of wall**	**Experiment 1**		**Experiment 2**		**Experiment 3**	
	Wood (ster)	Coal (kg)	Wood (ster)	Coal (kg)	Wood (ster)	Coal (kg)
Clay + straw wall	3	1,278	3	1,280	3	1,282
Brick wall	3	1,232	3	1,231	3	1,233
Fibrocement wall	3	1,666	3	1,658	3	1,665
Steel sheet + rice husk wall	3	1,050	3	1,054	3	1,052
2-layers carton	3	1,098	3	1,091	3	1,093

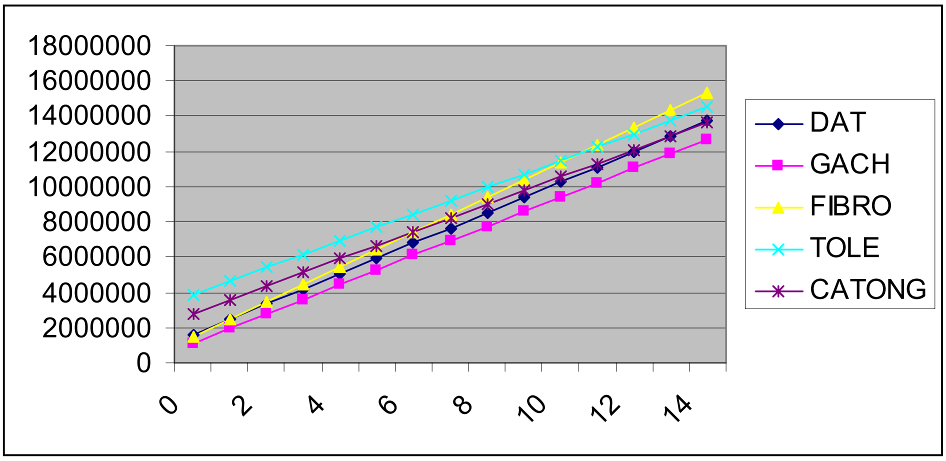
During test, we forced amount of used firewood as same, only amount of used coal is different. Thus, we just handled amount of coal for batches. Compare economic effectiveness of types of wall.

Table 7: Average cost of drying one batch for types of wall

Type of wall	**The average of dry cost (VNĐ/batch)**
Clay + straw wall	846,400
Brick wall	828,160
Fibrocement wall	991,560
Steel sheet + rice husk wall	759,760
2-layers carton	775,340

By table 3 and table 7, we replaced into equation $y=ax+b$ (a: cost of investing one type of wall in year, b : average cost of drying a batch; x : number of drying batches in year) to get the graph of comparison of economic effectiveness like Picture 3.

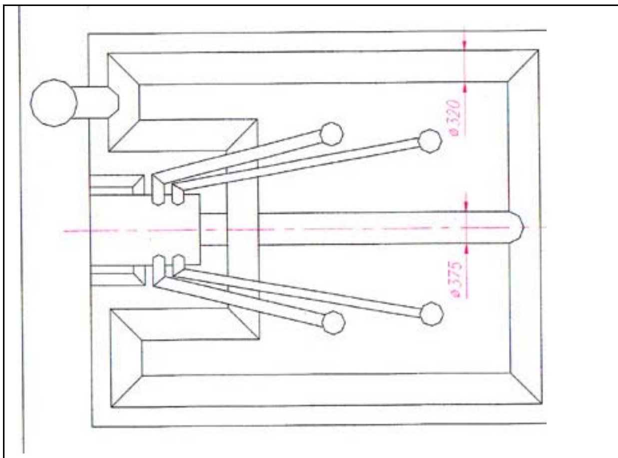
By the graph, we find out that with 1 to 14 drying batches a year, brick wall has lowest cost of drying. It's the most economical wall, thus should be used widely.



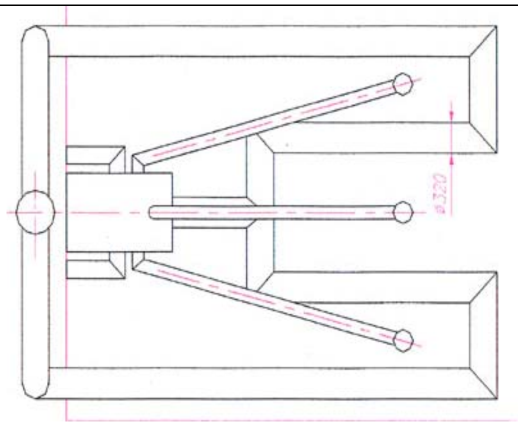
Picture 3

5. Conclusion

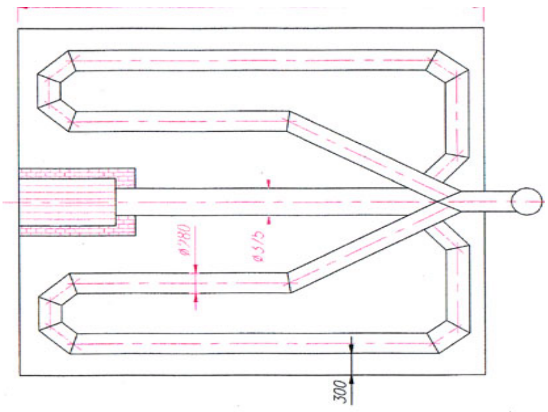
By calculating amount of heat losing through wall and test results with analyzing economic effectiveness, brick wall is most economical for 5x6m2 tobacco dryer if number of batches in year is 10 to 14 ones.



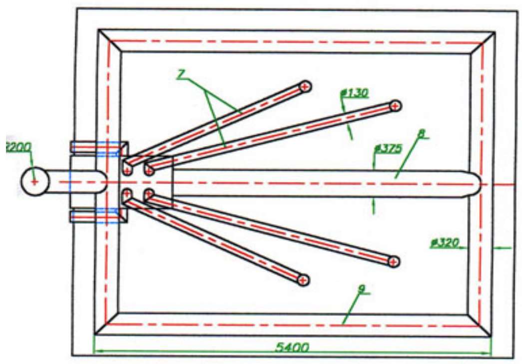
Picture 4: 3-pipes heat exchanger with chimney in one side.



Picture 5: 4-pipes heat exchanger.

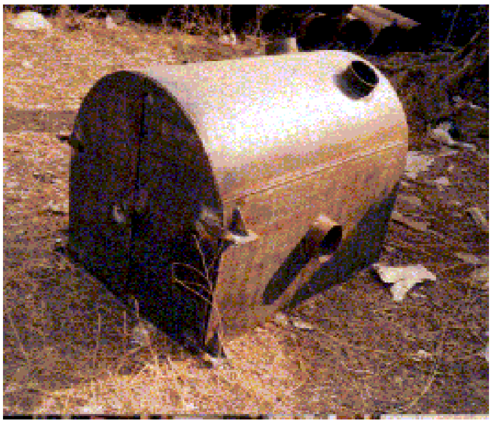


Picture 6: 5-pipes heat exchanger.

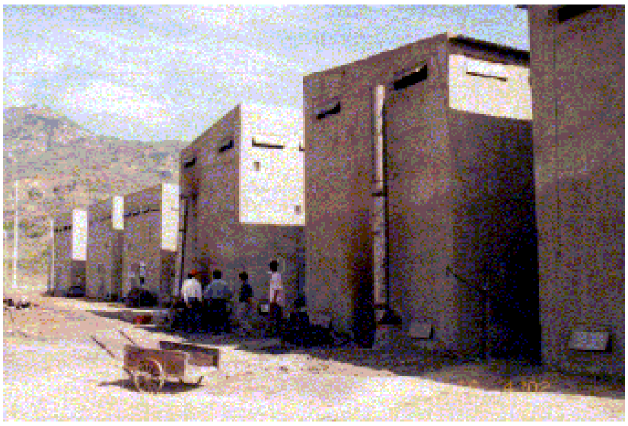


Picture 7: 3-pipes heat exchanger.

Picture 8: Fire - sustainable brick burner.



Picture 9: 2-layers steel burner



Picture 10: Tobacco leaf dryer group uses charcoal fuel

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