Determination of Moisture Content Profiles in Wood Drying

X.J. Li, Z. Cai, and F. Fu

Research Institute of Wood Industry, Chinese Academy of Forestry

USDA Forest Service, Forest Products Laboratory,

Outline

1. Introduction
2. Methodology
3. Materials and Methods
4. Results and Discussion
5. Conclusions

1. Introduction

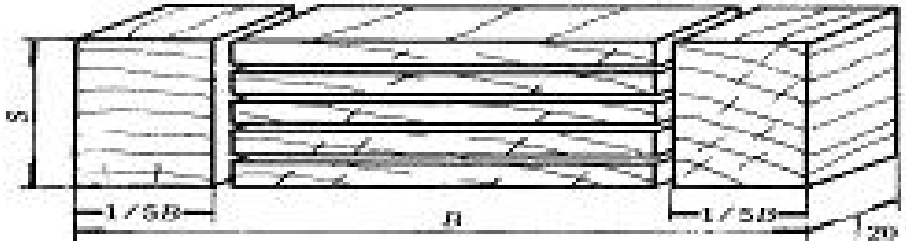
The electrometric method is the main one in practice

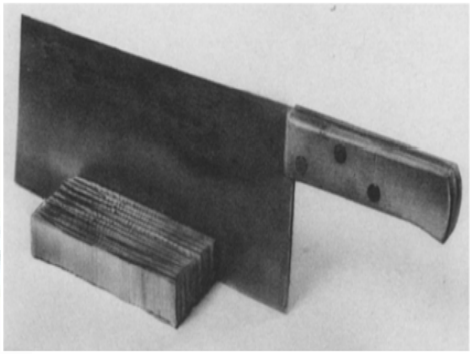
- Advantage
  - Quick
  - Easy
- Disadvantage
  - Limited range
  - Difficult to test MC profiles




OD method is the most precise one for the measurement of wood MC

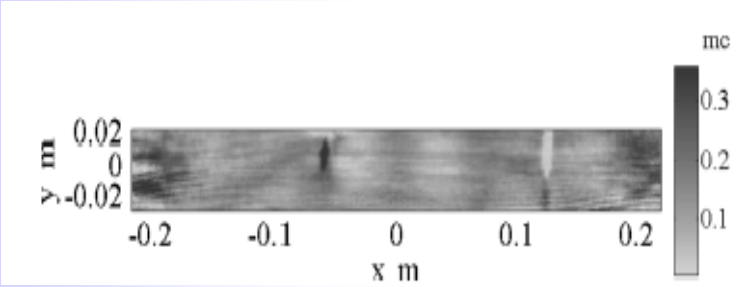
- Disadvantages
  - Long testing time
  - Difficult for on-line MC measurement
  - Cannot continuously monitor MC profiles





In recent years, CT scanning method has been applied to research the MC profiles in wood

- Advantage
  - Continuously monitor
  - Volumetric image



- Disadvantage
  - Very Complex
  - Expensive

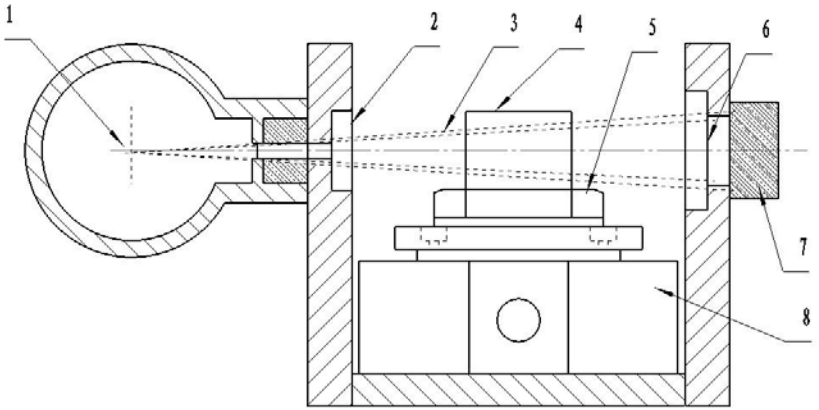
Our previous research shows X-ray scanning seems to be a good method to determine the MC profiles in wood.

Objective

To investigate the feasibility of using the X-ray scanning method to measure the MC profiles in wood drying

2. Methodology

$$I / I_0 = e^{-u\rho t}$$

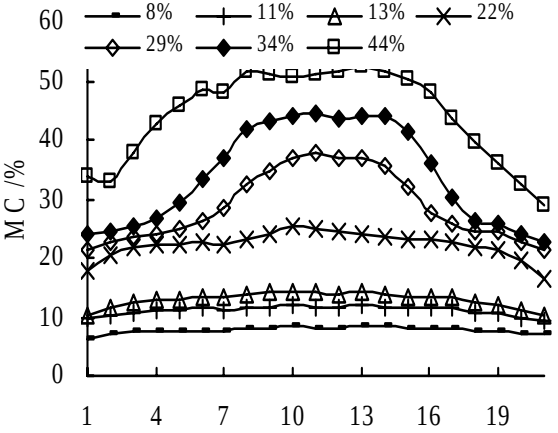


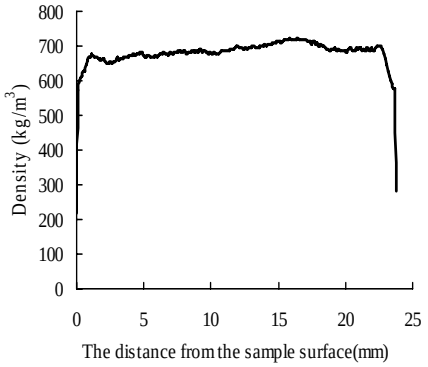
$$\rho = \frac{1}{\mu t} \ln\left(\frac{I_0}{I}\right)$$

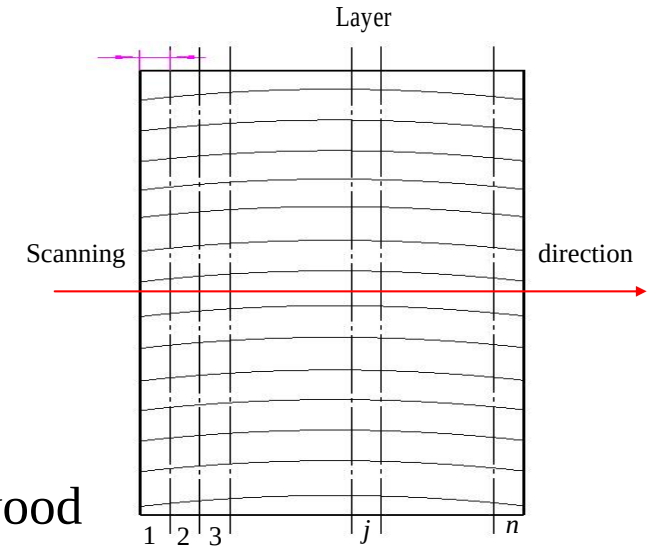
I_0 : Incident intensity
I : Transmission intensity
e : Natural logarithm base
u : Mass attenuation coefficient
t : Thickness
ρ : Average density

$$M_{(i,j)} = \frac{G_{(i,j)} - G_{(0,j)}}{G_{(0,j)}} \times 100\%$$

$$= \frac{\rho_{(i,j)} L_{(i,j)} T_{(i,j)} h_{(i,j)} - \rho_{(0,j)} L_{(0,j)} T_{(0,j)} h_{(0,j)}}{\rho_{(0,j)} L_{(0,j)} T_{(0,j)} h_{(0,j)}} \times 100\%$$







M : Moisture content (%)
G : Mass (g)
L : Length (mm)
T : Width (mm)
h : Thickness of each layer (mm)

i and j are the time and the number of layer in wood

3. Materials and Methods

3.1 Sample preparation

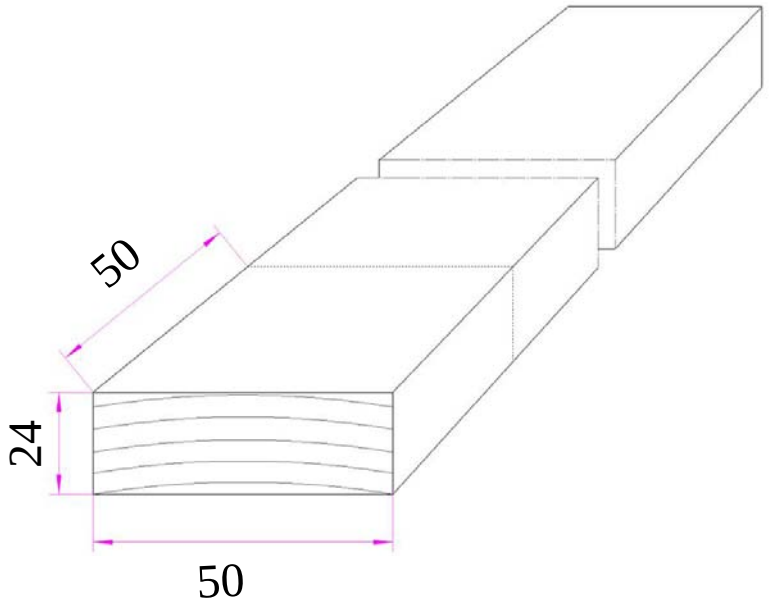
- Species

  Red oak Initial MC≈ 75%

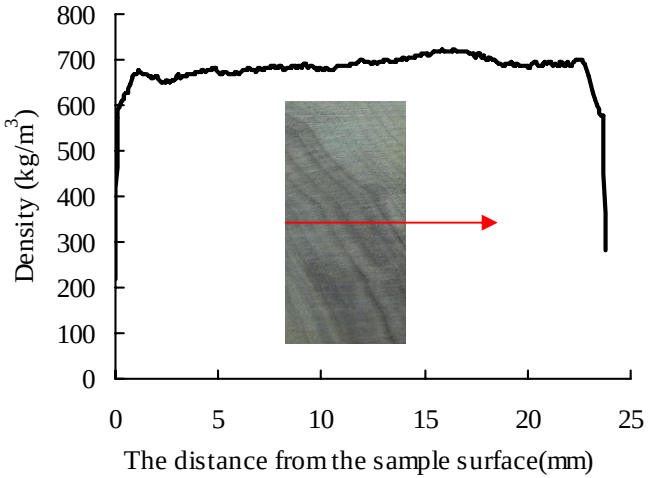
  Walnut Initial MC≈ 45%

- Dimension of samples

  50 (L)×50 (W)×24 (T) mm^3

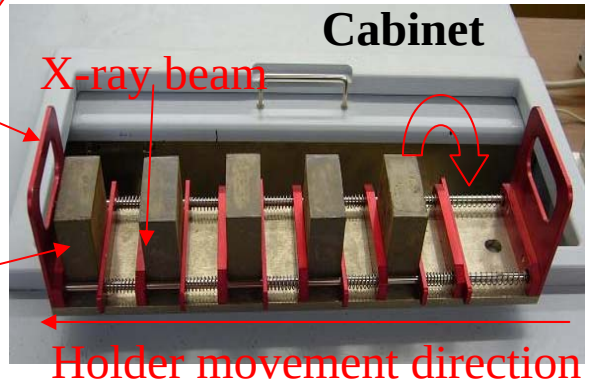


3.2 Experimental equipment



QMS X-ray density profiler

- The X-ray system
- Sample motion and stepping system
- Data collection system
- Control and data processing system

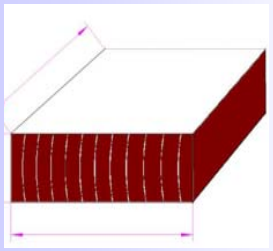


3.3 Procedures

Red oak
MC> 30% 60/50℃
MC<30% 60/45℃

Walnut
MC> 15% 60/55℃
MC< 15% 60/45℃

Sample sealed



Initial X-ray Scanning

Epoxy resin

Hot air drying

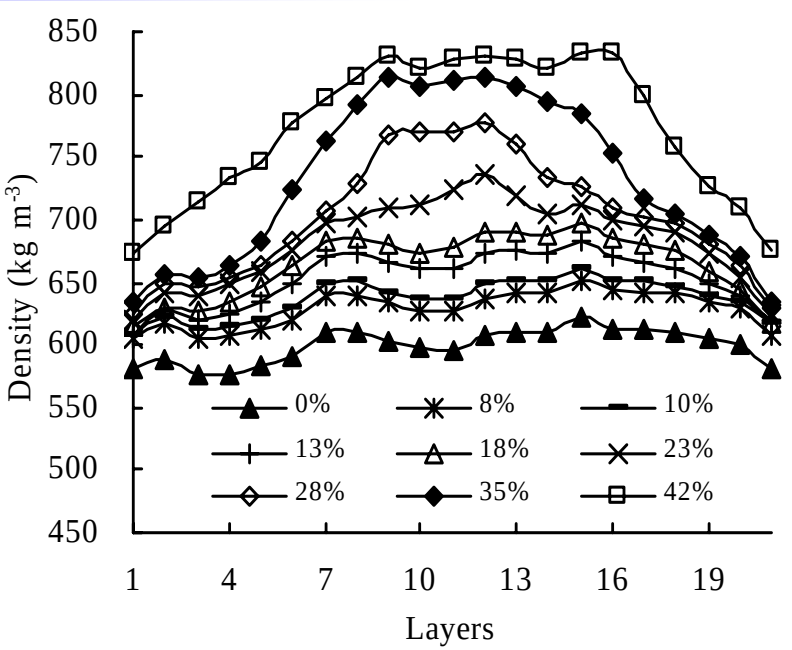
X-ray Scanning

X-ray scanning of oven-dried wood

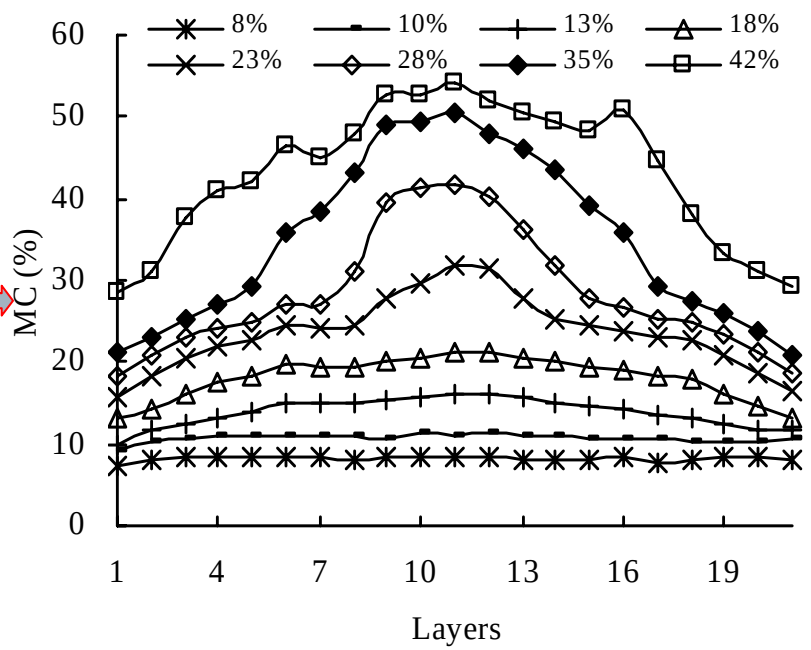
Data processing

MC profiles in wood

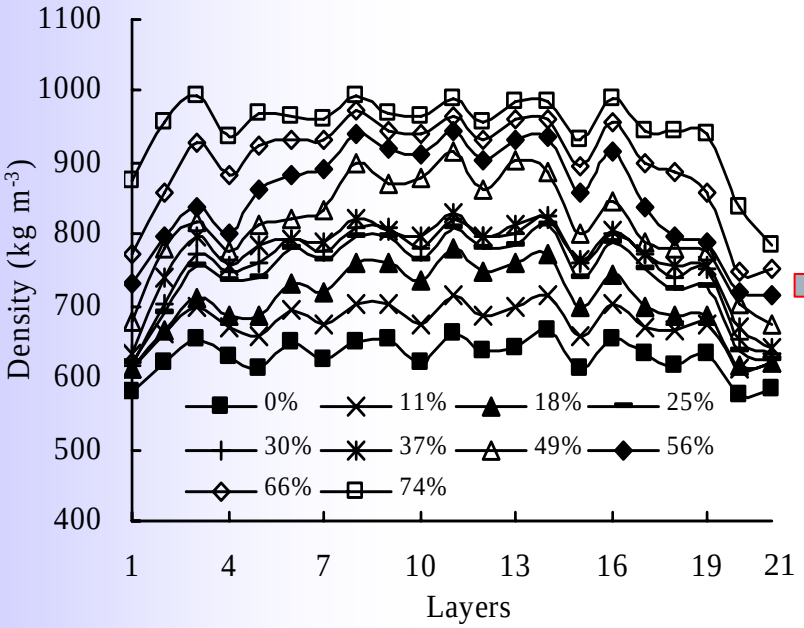
4. Results and Discussion



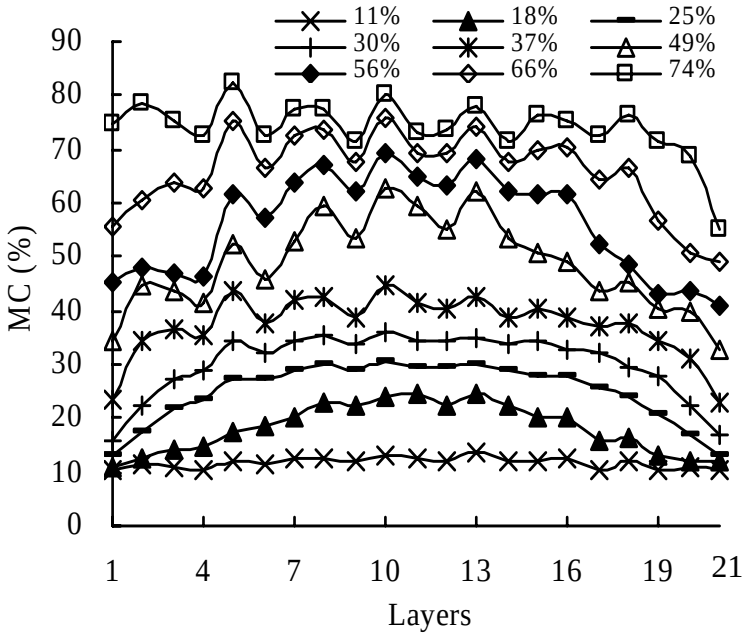
Density profiles of walnut



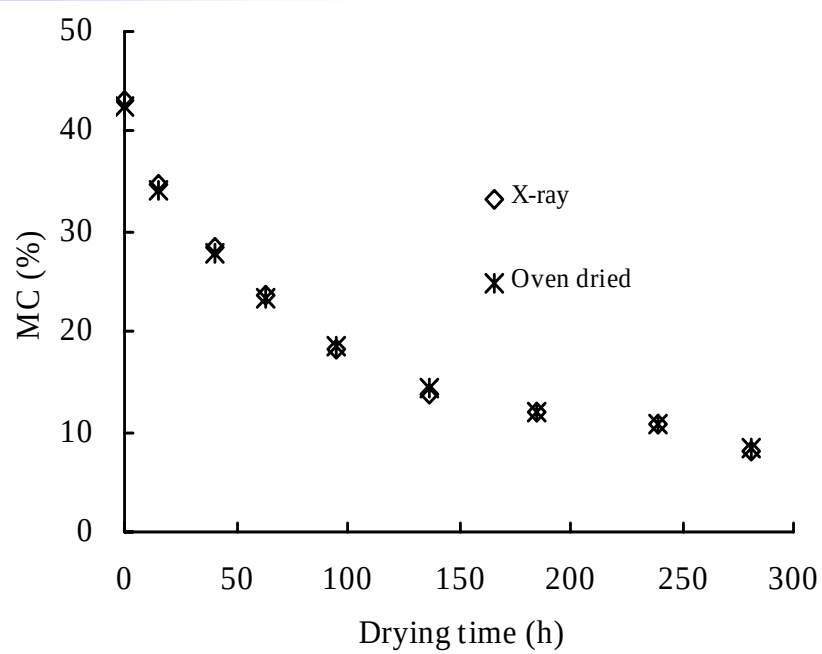
MC profiles of walnut



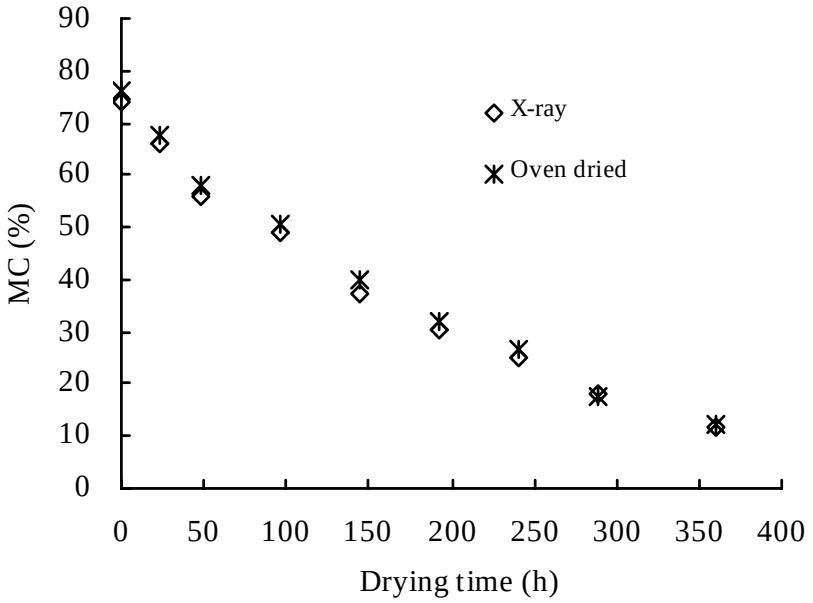
Density profiles of red oak



MC profiles of red oak



The comparison of average MC measured by X-ray and oven-dried methods for walnut during drying



The comparison of average MC measured by X-ray and oven-dried methods for red oak during drying

The comparison of average MC measured by X-ray scanning and OD methods and its correlation coefficient for walnut

Specimen number	Measured method	Time/h 0	15	41	63	95	137	185	239	281	R^2
		Moisture content/%									
W0	X-ray scanning	41.46	34.45	26.23	23.08	17.70	13.87	10.93	10.71	8.64	0.9992
	Oven-dried	41.26	34.02	26.41	22.93	18.17	13.81	11.35	10.70	8.31	
	MC Deviation	-0.21	-0.44	0.18	-0.15	0.48	-0.06	0.43	-0.01	-0.34	
W1	X-ray scanning	44.58	35.58	30.81	24.86	18.90	14.51	13.13	11.37	8.35	0.9976
	Oven-dried	44.32	35.51	30.04	24.66	19.02	14.33	12.28	10.35	7.71	
	MC Deviation	-0.26	-0.08	-0.77	-0.20	0.11	-0.18	-0.85	-1.02	-0.64	
W2	X-ray scanning	41.76	33.52	28.77	24.14	18.08	15.14	11.32	10.09	8.11	0.9865
	Oven-dried	39.62	31.56	26.80	22.60	18.16	15.09	11.43	9.72	8.04	
	MC Deviation	-2.14	-1.96	-1.96	-1.54	0.08	-0.05	0.11	-0.37	-0.07	
W3	X-ray scanning	46.33	36.50	28.81	23.91	19.73	13.90	12.14	10.79	8.85	0.9979
	Oven-dried	46.16	36.36	28.93	23.91	20.19	15.04	13.06	11.37	8.95	
	MC Deviation	-0.17	-0.14	0.12	0.00	0.46	1.14	0.92	0.59	0.11	
W4	X-ray scanning	40.32	32.24	27.34	22.61	16.00	13.65	12.13	11.01	9.55	0.9971
	Oven-dried	40.87	33.03	27.81	22.89	16.82	14.10	12.54	11.64	9.47	
	MC Deviation	0.55	0.79	0.47	0.28	0.82	0.45	0.41	0.64	-0.08	

The comparison of average MC measured by X-ray scanning and OD methods and its correlation coefficient for red oak

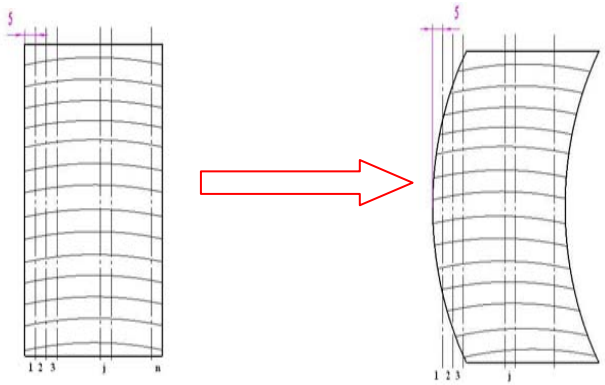
Specimen number	Measured method	Time/h: 0	24	48	96	144	192	240	288	360	R^2
		Moisture content/%									
O1	X-ray scanning	74.58	66.76	57.17	48.68	37.54	32.52	27.29	17.58	12.59	0.9959
	Oven-dried	76.44	68.22	58.87	49.77	39.58	33.18	28.11	17.39	11.96	
	MC Deviation	1.86	1.46	1.70	1.10	2.04	0.66	0.81	-0.19	-0.63	
O2	X-ray scanning	73.24	64.78	56.71	48.41	37.98	30.75	26.10	17.21	12.33	0.9884
	Oven-dried	76.13	67.57	58.94	51.19	40.93	32.22	27.71	17.94	12.41	
	MC Deviation	2.89	2.80	2.24	2.79	2.94	1.47	1.60	0.73	0.09	
O3	X-ray scanning	73.21	66.00	56.09	49.03	38.63	30.09	23.62	16.29	11.71	0.9929
	Oven-dried	75.58	68.09	58.02	50.44	41.56	31.47	24.70	16.64	11.57	
	MC Deviation	2.37	2.09	1.93	1.41	2.93	1.37	1.08	0.36	-0.13	
O4	X-ray scanning	72.08	63.70	53.67	45.89	34.85	27.59	22.30	16.25	11.65	0.9913
	Oven-dried	74.84	66.06	55.62	47.86	37.50	29.05	23.65	16.88	11.72	
	MC Deviation	2.75	2.36	1.96	1.97	2.65	1.46	1.35	0.64	0.07	
O5	X-ray scanning	75.70	67.27	57.36	51.43	38.46	32.28	26.33	18.84	13.59	0.9951
	Oven-dried	77.98	69.32	57.85	52.39	40.61	33.30	27.79	19.25	13.30	
	MC Deviation	2.28	2.06	0.49	0.95	2.14	1.01	1.46	0.41	-0.29	

Problems

- Non-uniform shrinkage probably induce some errors in the determination of the MC profiles during drying.

- Serious warping deformation of wood during drying probably result in not very good measurement results

Initial condition



Oven dried condition

5. Conclusions

- X-ray scanning method can be used for measuring the MC profiles in wood drying

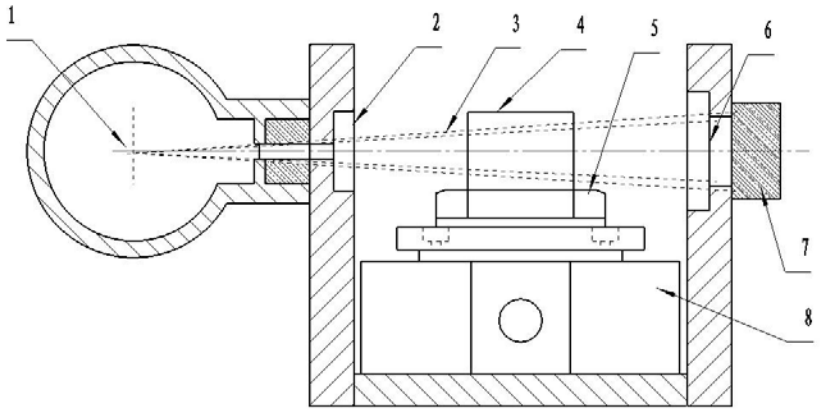
- Within a range of MC from 8-78%, the maximum measured MC deviation is less than 3%

- The square of correlation coefficient of MC measured by OD method and X-ray scanning method is beyond 0.98;

- The method can provide a very useful tool for understanding MC profiles and moisture movement within wood during drying

Non-destructive method of measuring a moisture content profile across a hygroexpansive composite material.

Z. Cai, US Patent 7,571,061 B2



Thank You !