



# Final Drying of Thin Fleece Layer to Prevent Humidity Condensation

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**Abstract:** The paper presents methods of final drying of thin fleece layer after outlet from drying chamber, to prevent the water vapor condensation from material packed in impermeable foil. There are presented results of numerical simulations of possible solutions. Suitable design is not expensive and meets all operational requirements. The supplementary both operational and investment costs are very low.

**Keywords:** Fleece, Numerical Flow Simulation, Drying

## 1. Introduction

The paper presents methods of final drying of thin fleece layer after outlet from drying chamber, to prevent the further water vapor condensation from material packed in impermeable foil. There are presented results of numerical simulations describing possible realizations.

## 2. Problem Description

### 2.1. Situation

Produced fleece is composed from several kinds of elementary yarn layers, made by standard procedures from molten polymers. Manufactured layer is going through the plant [1], then is calendered, at the same time it is point wise smelted by hot calendering cylinders [2]. Then a wet finish is laid on, the material is dried at 70°C approx., coiled at 40°C approx. and packed in vapor permeable and water impermeable foil. So the inside temperature of wet air is 35°C approx., its relative humidity is high, corresponding to the state at the outlet from the dryer. Subsequently – in the store and during the transport, first of all during the cold season – some water vapor is condensed inside and the product is reclaimed as “contaminated by water”.

The general task is, “to reduce the temperature of produced fleece”. The aim of this study is to design a suitable system, how to prevent the water vapor condensation under covering

foil. Presented solution shows that the originally prescribed task is not good, the better should be “to reduce the water content in the air contained in the treated fleece layer”.

### 2.2. Theory of Wet Air

The wet air is composed from dry air and water vapor. The dry air is the mixture of so-called real gases (first of all O<sub>2</sub>, and N<sub>2</sub>), their characteristics are very close to the so-called ideal gas. So this mixture is considered as constant, using the characteristics of the dry air.

On the other hand, in range of temperatures and pressures, usually used in systems of HVAC, hot air dryers etc., the air humidity can be present in any of three state phases. Also for water is not possible to use simple laws of ideal gas, for the practical use the diagram of wet air is used, as presented in many text-books, manuals, [3] etc.

It is supposed that the wet air pressure is constant (atmospheric, 100 kPa approx.), small differences due to the weather, altitude, pressure or suction side of the fan etc. can be neglected for standard operational purposes. The state of wet air is then explicitly given by the temperature  $t$  (°C) and relative humidity  $\phi$  (-), both parameters are simply measurable. For creation of balance equations are better parameters of enthalpy  $i$  (J/kg) and water content of humidity in grams per kilogram of dry air  $x$  (g/kg). The recalculation between  $T$ - $\phi$  and  $i$ - $x$  is simply made by the diagram of wet air.

The balances of mass and energy are simple

$$Mv \cdot (x_2 - x_1) = M_p \quad (1)$$

$$Mv \cdot (i_2 - i_1) = Q \quad (2)$$

where

1, 2 inlet, outlet

$Mv$  (kg/s) air in drier

$x_1, x_2$  (g/kg) water content in air (from diagram)

$M_p$  (g/s) dried-up water content

$Q$  (W) heat input for air warming

### 2.3. Process in Hot-Air Dryer Description

The next diagram of wet air on the Figure 1 describes the initial hypothesis of possible solution.

1 – Air in the surrounding 25°C, 30%, variation 20-30°C, 20-50%.

2 – During the so-called adiabatic drying the air in dryer is wetted along  $i = \text{const}$  (the material is dried) and a part of it is going out. Temperature 70°C, water content 23 g/kg.

Remark: It could be possible to dry more at lower temperature, so the air temperature becomes lower. By this the air flow (kg/s) necessary for drying is lower, but at the same time the water content ( $x$ ) of outlet air is increased and so is increased the wet point temperature, too. To be sure, that the dried material will not be wetted again by any random changes of air parameters during the operation, the final relative humidity will not be higher than 90%.

3 – One part of this wetted air 2 is going out and is replaced by fresh (more dry) air 1 from the production shop; the rest is circulating in the dryer.

Remark: Usually given volume flows ( $\text{m}^3/\text{s}$ ) are not unique; they depend on the temperature and pressure, which are different in different points of the drying plant. It is necessary to add air temperature, pressure and humidity and all to recalculate on mass flows. Therefore it is better to use directly mass flows, independent on state values.

4 – The mixture 3 is heated on the inlet temperature of dryer 80°C.

This point 4 is given as the point of intersection of conditions  $x_3 = x_4$  (dry heating) and  $i_4 = i_2$  (adiabatic drying). Then it is supposed thermally insulated drying plant – the air hands over a part of its enthalpy into the dried material for water evaporation and evaporated vapor is going out together with drying air, so the air enthalpy before and after plant does not change.

5 – The temperature of fleece volume after drying and before packing is supposed as 35°C approx. It means that any next fleece cooling happens during its movement in the

surrounding air. It is supposed that after drying plant is not any fluid water in the nonwoven, so that the water content in the air, contained in the fleece volume remains constant during such cooling (there is not any water condensation during the cooling), then the relative humidity of the air is increasing.

6 – The wet point temperature  $t_6 = 26^\circ$  for the air 5 is a checking value. The air closed in the packed fleece volume is not more dried, so after temperature decreasing in the surrounding during storage and transport under  $t_6$  some water will be condensed under packing.

7 – The air 5 in the fleece volume it is necessary should be replaced by more dry air 1 from the surrounding production hall. Its wet point temperature is  $t_7 = 8.5^\circ\text{C}$ , so the danger of vapor condensation under packing is not so high.

8 – If it would be not enough, it is possible to use the air dried by cooling on the (standard) wet point temperature of  $+3^\circ\text{C}$  (to prevent the icing of the condensed water in the drain) and the danger of vapor condensation in packed fleece will be yet lower. There is the question, if the increased costs for this technology (both investments and operation) will be efficient.

For better orientation in the complicated Figure 1 the main parameters of above mentioned operating states of air are summarized in the Table 1.

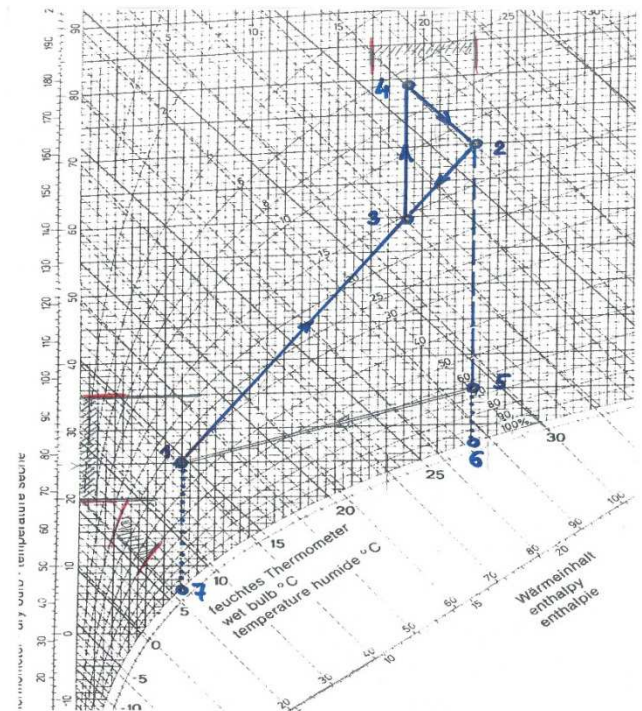


Figure 1. Diagram of wet air – drying process.

Table 1. Air parameters during drying process.

pos	temp	relat hum	water cont.	wet point	enthalpy	remark
	°C	%	g/kg	°C	kJ/kg	
1	25	30	6	6.5	40	hall
2	70	12	23	27.5	135	from dryer
3	59	15	19	24.0	110	mixed 1+2
4	79	7	19	24.0	130	to dryer

pos	temp	relat hum	water cont.	wet point	enthalpy	remark
5	35	65	23	27.5	95	cooled out
6	27.5	100	23	27.5	88	wet point for 5
7	6	100	6	6.0	7	wet point for 1
(8)	3	100	3	3.0	3	Artificial drying

## 2.4. Permeability

So-called air permeability is defined as volume flow ( $\text{m}^3/\text{s}$ ) through sample area ( $\text{m}^2$ ), also it is the flow velocity ( $\text{m/s}$ ). the flow resistance [4], [5] etc. contains the linear term, typical for instance for liquid infiltration at low velocities (Darcy's law) and the quadratic term, typical for flow around bodies and in channels (Weissbach's or Moody's law).

$$\Delta p = C_2 \cdot \rho/2 \cdot t \cdot w^2 + \mu / \alpha \cdot t \cdot w \quad (3)$$

where

$w = V/S$  ( $\text{m/s}$ ) flow velocity  
 $V$  ( $\text{m}^3/\text{s}$ ) volume flow (measured)  
 $S$  ( $\text{m}^2$ ) flow area  
 $t$  (m) thickness of permeable layer  
 $\rho$  ( $\text{kg/m}^3$ ) medium density (for air 1,2)

$\mu$  (Pa.s) dynamic viscosity (for air  $1,805\text{e-}5$ )  
 $\alpha$  ( $\text{m}^2$ ) unknown permeability parameter [4]  
 $C_2$  (1/m) unknown permeability parameter [4].

In a real permeable structure usually exists any combination of those limiting cases (linear, only, or quadratic, only term).

Two unknown permeability parameters  $\alpha$  and  $C_2$ , dependent on the structure of observed permeable layer, is possible to evaluate for the use in numerical flow simulation of permeable layers. From measured flow characteristic  $V = f(\Delta p)$  or  $w = f(\Delta p)$  [6] should be created the inversed resistance characteristic  $\Delta p = f(w)$ , to get the function formally similar with (3). This function is on the Figure 2 together with substitution by the polynomial of the second order  $y = f(x^2, x)$ , here as

$$\Delta p = 1.6309 \cdot w^2 + 23.727 w - 11.235 \quad (4)$$

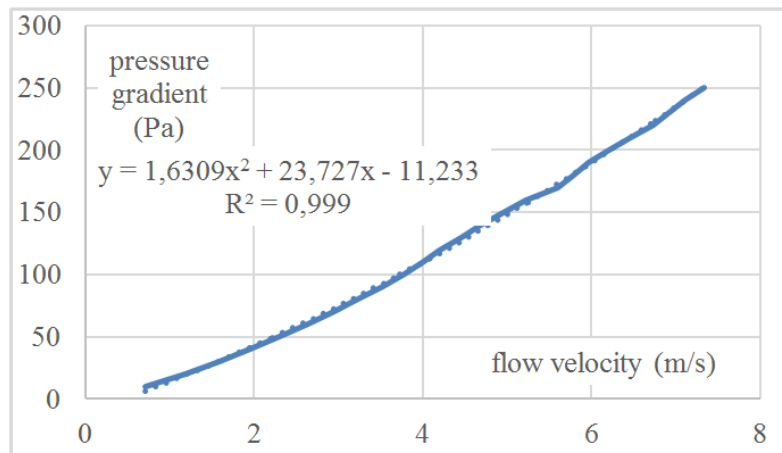


Figure 2. Resistance characteristic of observed nonwoven.

Comparing the coefficients of linear and quadratic terms in both quadratic functions (3) and (4) the two unknown permeability parameters are

$$C_2 = 1.6309 / (\rho/2 \cdot t) = 1.045\text{e+}4 \text{ (1/m)} \quad (5)$$

$$\alpha = \mu / (23.727 \cdot t) = 2.926\text{e-}4 \text{ (m}^2\text{)} \quad (6)$$

The absolute term in the equation (4) should be equal to zero (for zero flow there is zero resistance, too). It is an error of simulation, evaluation or measuring – the value of 11 Pa from the used range of 250 Pa means the acceptable relative error of 4.5%, comparable with measuring error of standard measuring devices.

Measured values of flow through the nonwoven of  $15 \text{ g/m}^2$  at different pressure gradients are used from [2] for not finished fleece. On finished fleece another permeability parameters are expected, but for testing of designed procedure it is neglected here.

The presented method of permeability parameters determination by evaluation of measured data was used in many applications for thin and thick layers, [7], [8], [9] etc. For samples of simple geometries (perforated sheet etc.) the flow rate can be modeled and permeability parameters evaluated.

## 2.5. Possible Realization

Probable reason of above described vapor condensation on the inside of the packing foil is the fact, that the air, contained in the fleece volume at the outlet from the dryer is quite warm and relatively very wet (point 5 on the Figure 1). At high operational velocity of the plant (typically  $15 \text{ m/s}$ ) is hardly any time for “breathing”, i.e. for at least partial exchange of wet and warm inner air by cooler and more dry air from the surroundings. The time for passing the fleece between dryer and packing is in this build-up area of  $0.3 \text{ s}$  approx.

The packing foil is thin. Therefore it is supposed that the foil temperature will be the same as surroundings temperature. If the surrounding temperature is decreasing under the wet point temperature of inside air under the packing, on the inner side some water vapor is condensed. Because the foil is permeable for water vapor but impermeable for liquid water, the condensate remains under the packing.

To suppress this problem there are defined several hypothesis below. It should be to note here, that the danger of condensation is suppressed, but not fully removed without next high costs of investment and operational, necessary for drying at very low wet point temperature.

Spontaneous – during the fleece movement in the surrounding air some exchange of inside and outside air is proceeded, but it is not enough time for it, due high production velocities of the plant.

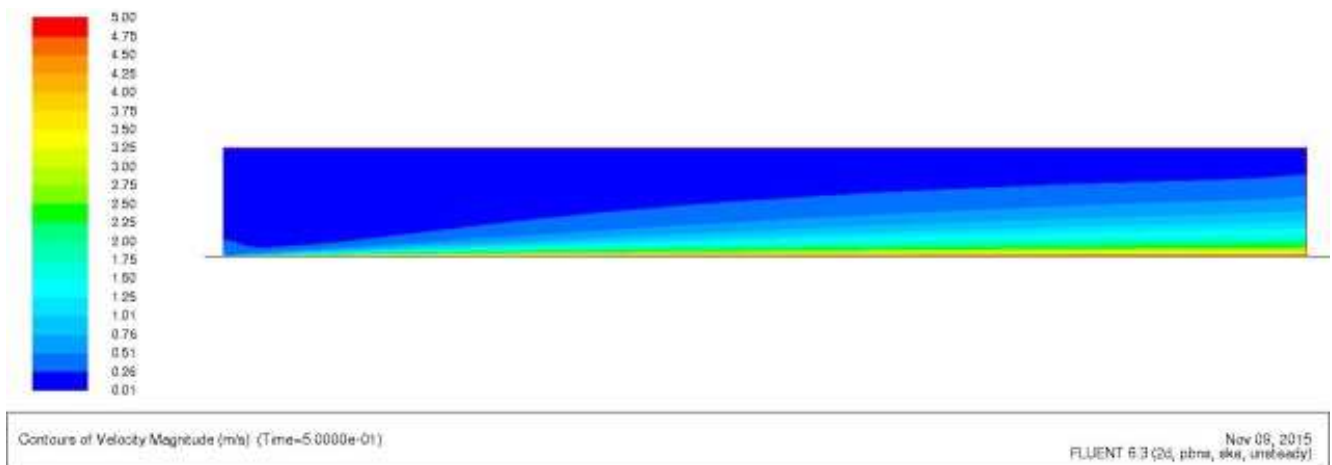
Water cooling of supporting and driving cylinders – not possible. During the summer period at specific conditions of outer air the cooled surface will become wet by condensation of humidity of outer air – the fleece will be more wet, not

dry. And more, the costs of spacious cylinders are too high.

Next drying chamber – the air in the nonwoven at the outlet from actual dryer is too warm and wet. To use any second stage of drying, but it is not place for installation in the actual equipment, regardless of next investment costs.

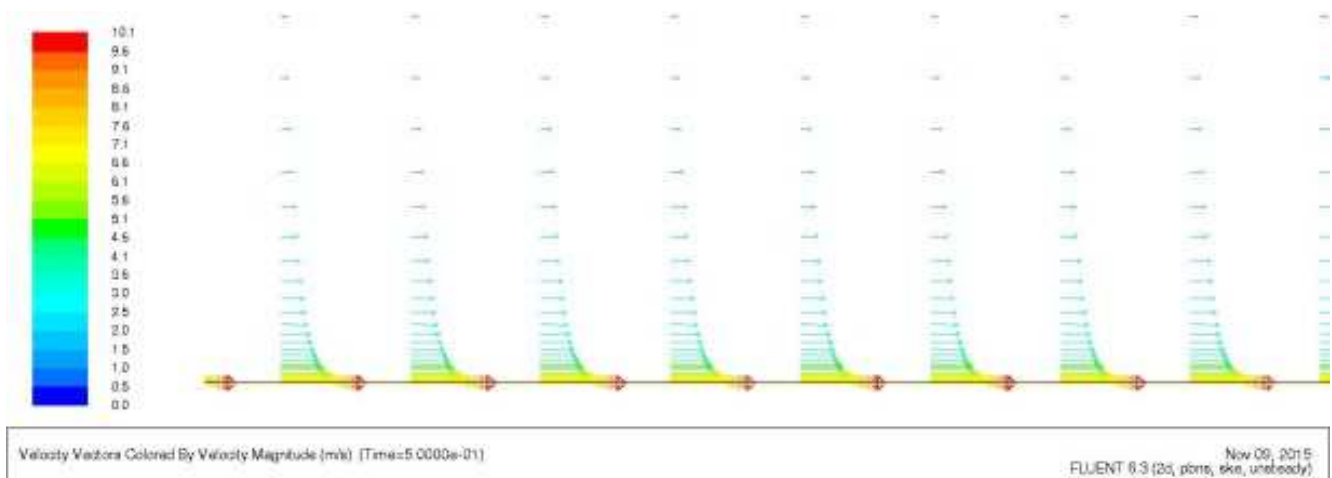
Transverse blowing through fleece thickness - just before the fleece coiling to install transverse orifice for air blowing through the fleece thickness. In that way the warm and wet air inside the nonwoven volume is quickly exchanged by dry and cold air from the surrounding. Formally identical with second dryer, but very simple.

The intensive effect is achieved by placement of the transverse orifice close to the nonwoven surface, but there is a danger of contact, excessive abrasion, and subsequent dust creation or as far as damage. Some slight contact never mind, the permanent forced contact should be prevented. On the other side, at any higher distance between orifice and nonwoven surface the blowing effect is decreasing substantially. But it is fact that any blowing improves the actual state and the danger of condensation will be decreased.



**Figure 3.** Velocity field – global view.

Due to the air viscosity, on the Figure 3 the warmer boundary layer is arising in the surroundings along moving fleece.



**Figure 4.** Directional field.



Another illustration of the previous effect – air acceleration and warming by the movement of warm fleece.

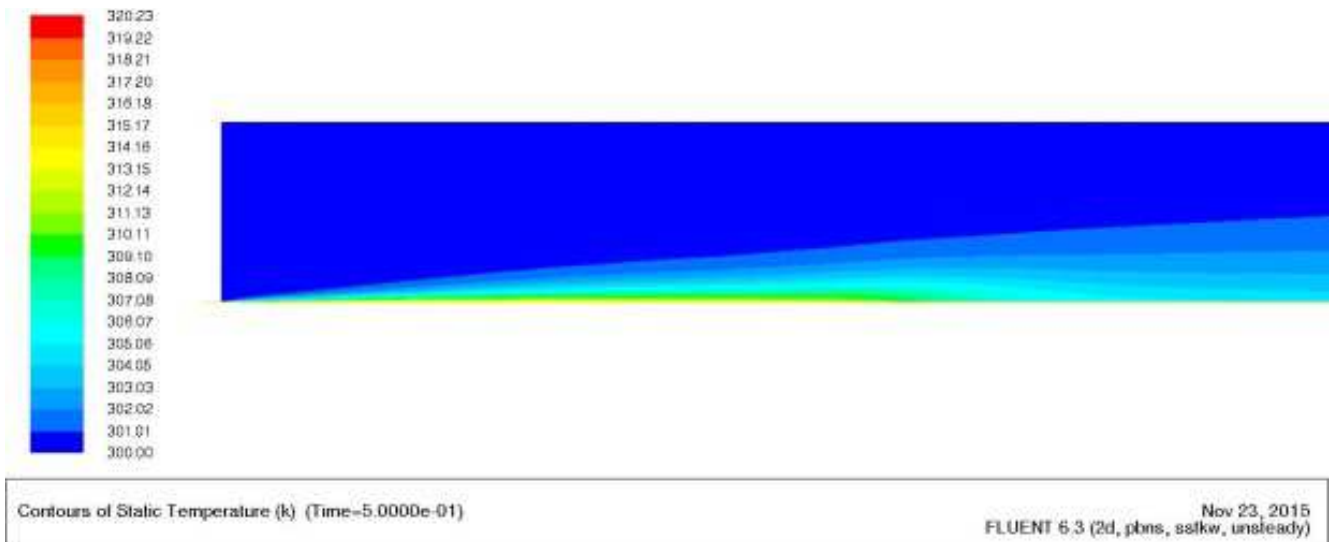


Figure 5. Global temperature field.

## 2.6. Simulation

Verification of this hypothesis of air exchange in the fleece layer by outside air, using the transverse air blowing is numerically simulated on planar model (for the dimension of 1 m perpendicular to the plane) – it means that for the fleece of several meters width there are neglected slightly different conditions at edges. Permeability parameters are used from [2], see also the Par. 2.4. In the free thickness of 0.26 mm (not pressed) there is 20% of fibers and 80% of air approx.,

so it is possible to simulate the movement of air layer, only, with defined so-called “porous jump”.

### 2.6.1. General View

As the first step the natural cooling of impermeable fleece layer moving in the surroundings (velocity of 10 m/s), is solved.

The standing surroundings is warming step by step by the heat from the fleece volume, in the end part (right) the both temperatures (fleece and surroundings) are identical.

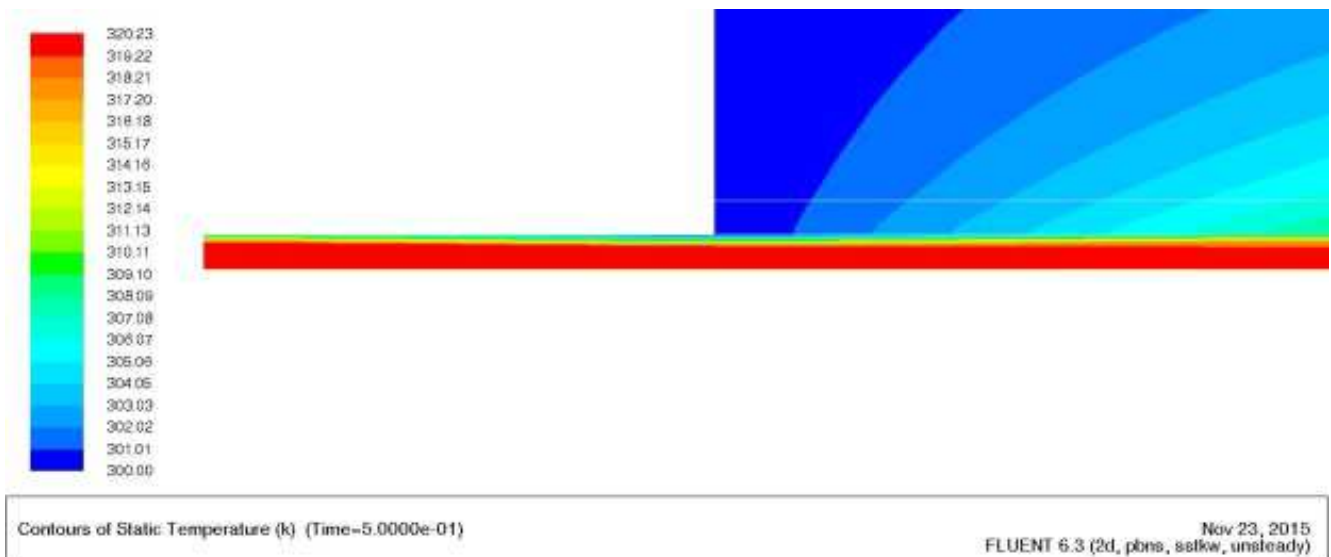


Figure 6. Temperature field in the inlet part.

The detail of the beginning warming of cold surrounding air by warm fleece.

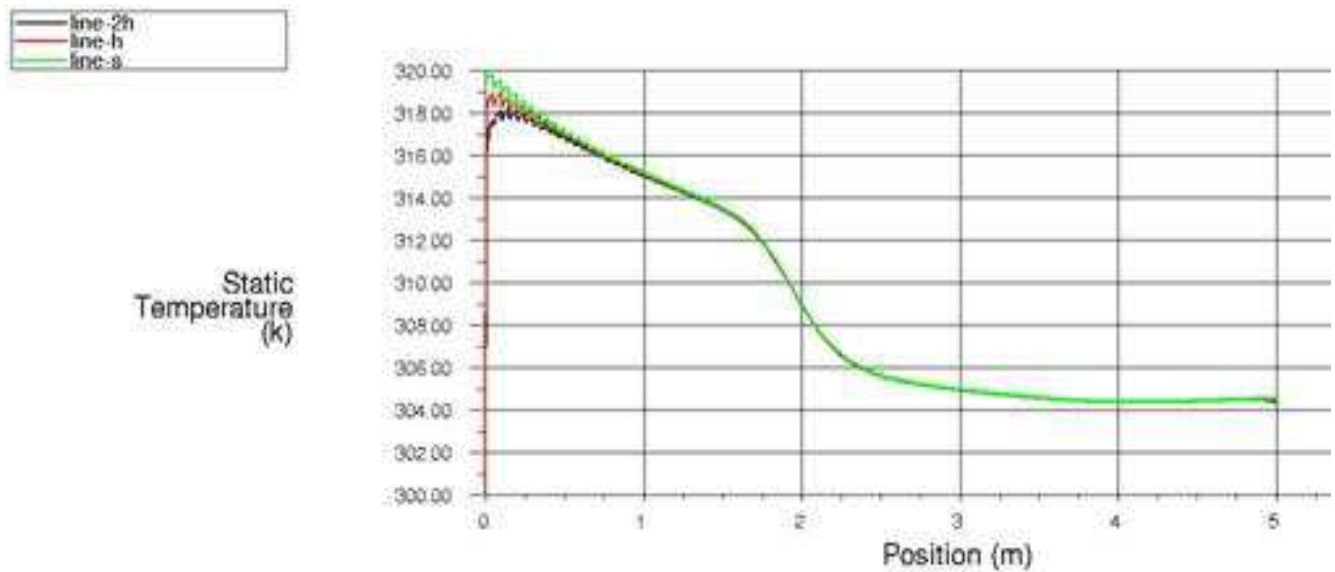


Figure 7. Temperature profiles in the fleece thickness.

Here are presented three cross sections:  $s$  = middle of thickness,  $h$  = upper surface of the fleece,  $2h$  = free surrounding at  $h$  from the upper fleece surface. Except the short starting part all profiles are identical.

This beginning part is up to 0.5 m approx. from the model inlet (left). Really, the fleece is going out from the drying chamber and moves in the free surroundings.

The fleece is cooling after some temperature gradient up to the distance of 1.5 m approx.

In the following part, up to 2.3 m approx., the fleece cooling is proceeded at higher temperature gradient.

Finally, the temperature gradient is decreasing, the fleece cooling is getting slow, because the air layer, moving together with fleece, is warmed now. The cooling is finished at the temperature of 304.5 K.

Probably, the fleece cooling is influenced by heat convection from the fleece into the surroundings and also by mixing of the cold air in the surroundings with warmer air in very airy fleece thickness, due to turbulences and cross movements of the fleece. Therefore a model with two kinds of air (fleece and surroundings) could give more correct result.

#### 2.6.2. Nozzle of 20 mm

Ten different cases approx. were solved with various initial conditions. The typical main results are following:

In one case, only, there is used air pressure of 100 Pa, due to low air cooling all other cases use the higher air pressure of 1 kPa.

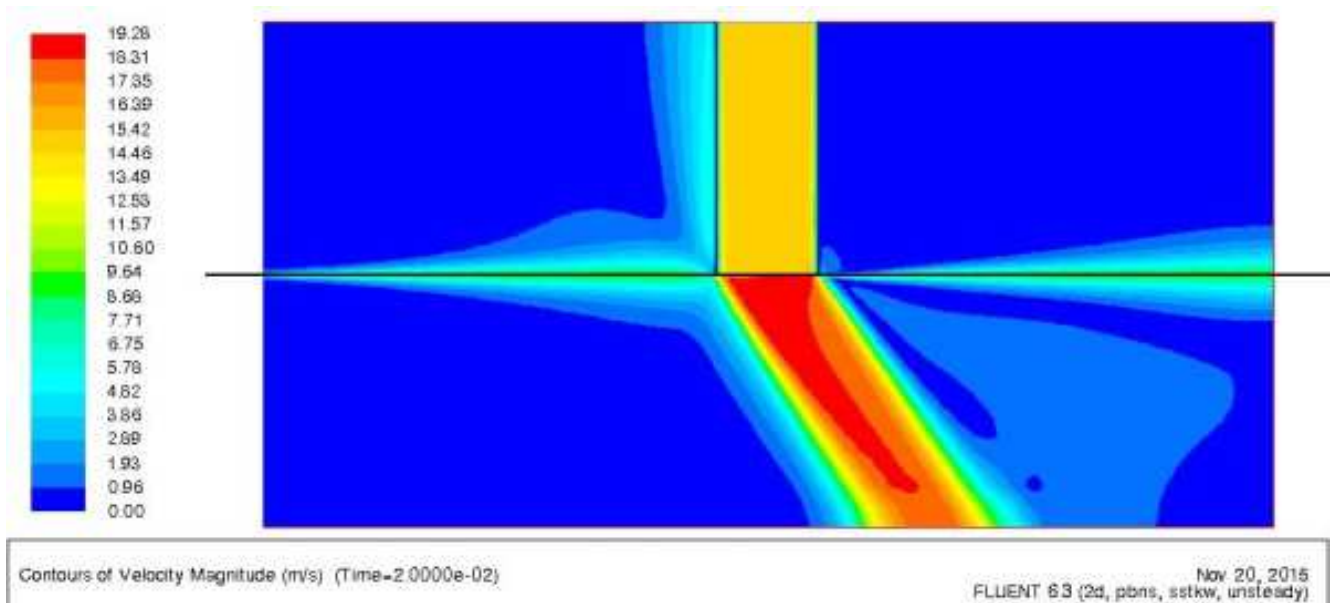
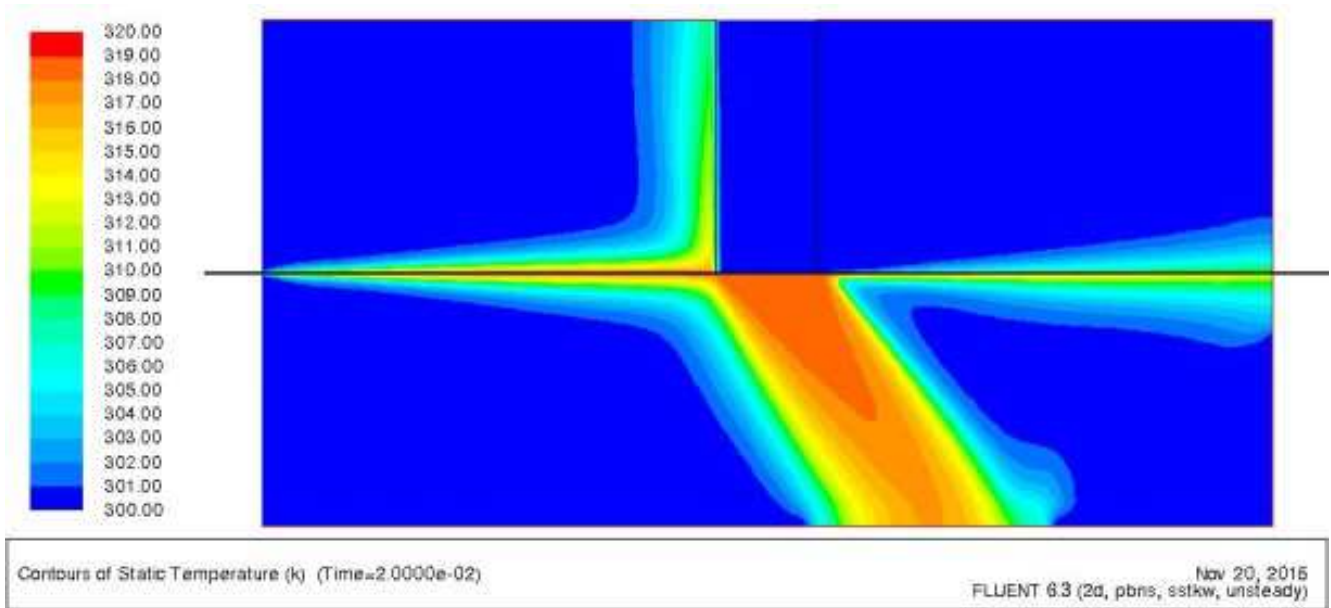


Figure 8. Velocity field.

Less expressive flow in the wake below.



**Figure 9.** Temperature field.

The fleece velocity of 10 m/s in general, in one case, only, the velocity 16 m/s was used. Different nozzle orifice width of 20-40-60 mm was used.

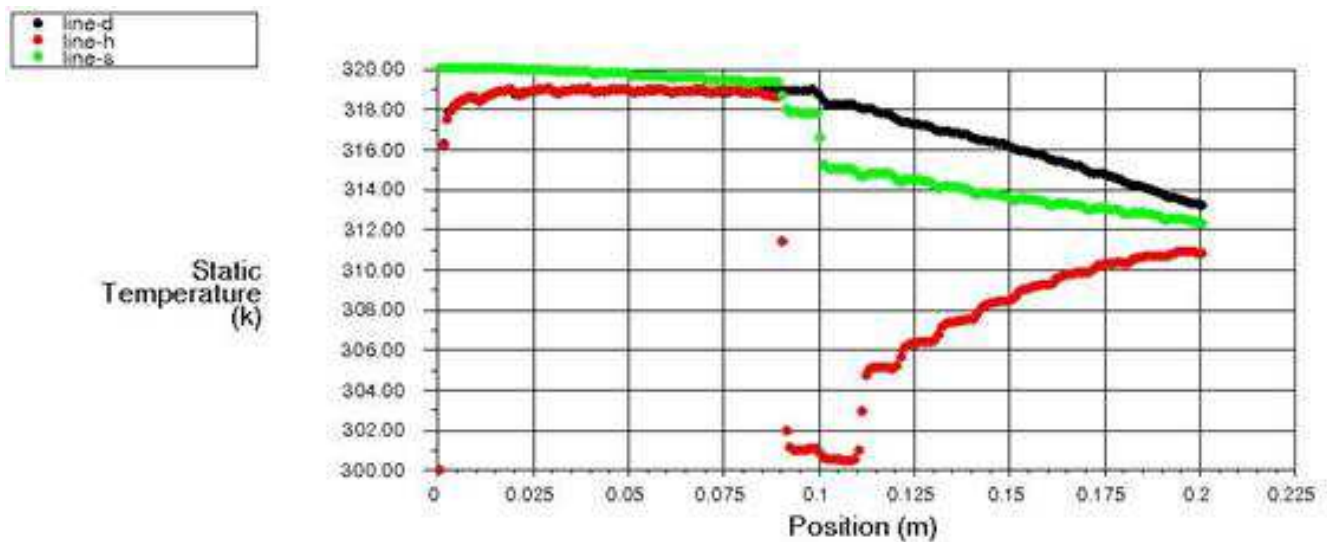
Calculated power is theoretical, as product of volume flow and pressure difference, for comparison of individual solved cases, only. To get a real value, it is necessary to divide the result by effectivity, for fans is low in general, under 50%.

Specific power is defined as rate of theoretical power and drop of temperature. For nozzles 40 and 60 mm the value is higher, but not 2-3 times, then the case of more nozzles is more effective, needs not too much power.

With increased fleece velocity the specific power is increasing, too, but not so quickly as the velocity increasing.

As an illustration here are presented velocity and temperature fields for one of solved cases (nozzle 20 mm).

The warm air from the fleece volume is blown out by the cross flow of blowing air. The direction is given as vector sum of fleece velocity and cross flow velocity.



**Figure 10.** Temperature profiles.

In the fleece thickness three temperature profiles are observed: d=down, h=up, s=middle. The highest differences in the area of the cross flow, later the temperature of the fleece volume is more uniform.

Undulated profile is the consequence of very coarse mesh and long time of the solution.

### 2.6.3. Nozzle of 60 mm

This nozzle orifice is 3x larger, the character of the flow field is similar, the flow under fleece is more compact, the final temperature is lower, see the Figure 11 to 13.

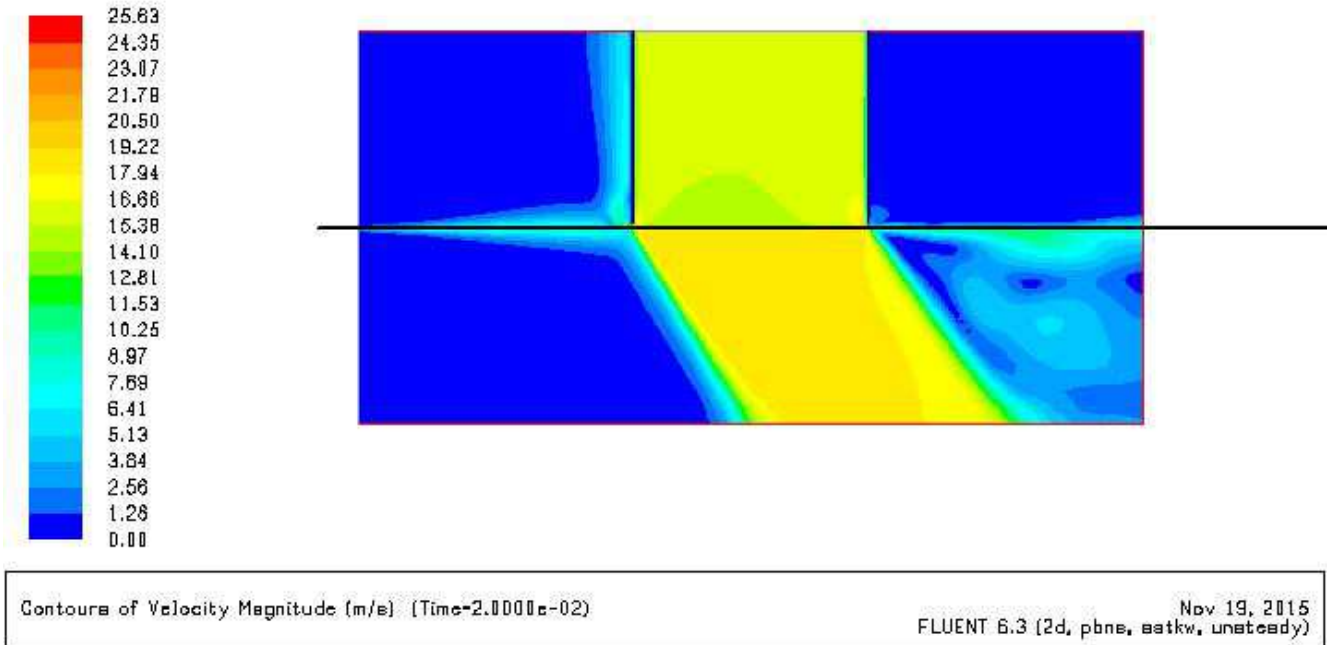


Figure 11. Velocity field.

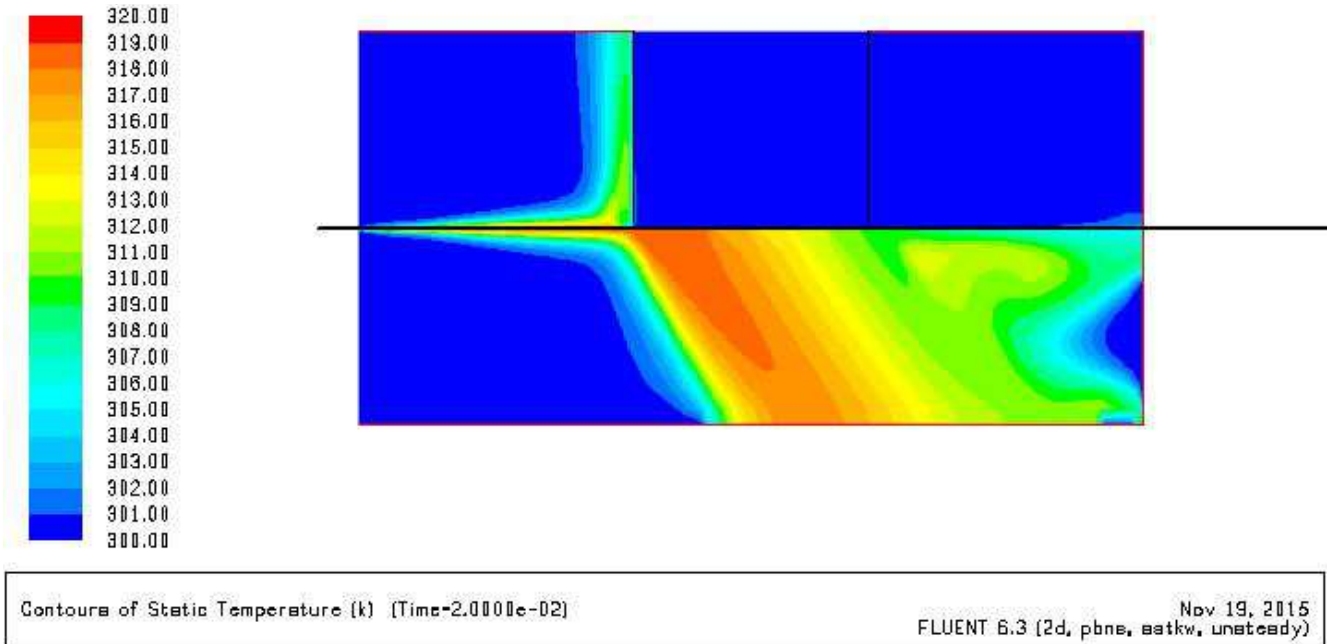


Figure 12. Temperature field.



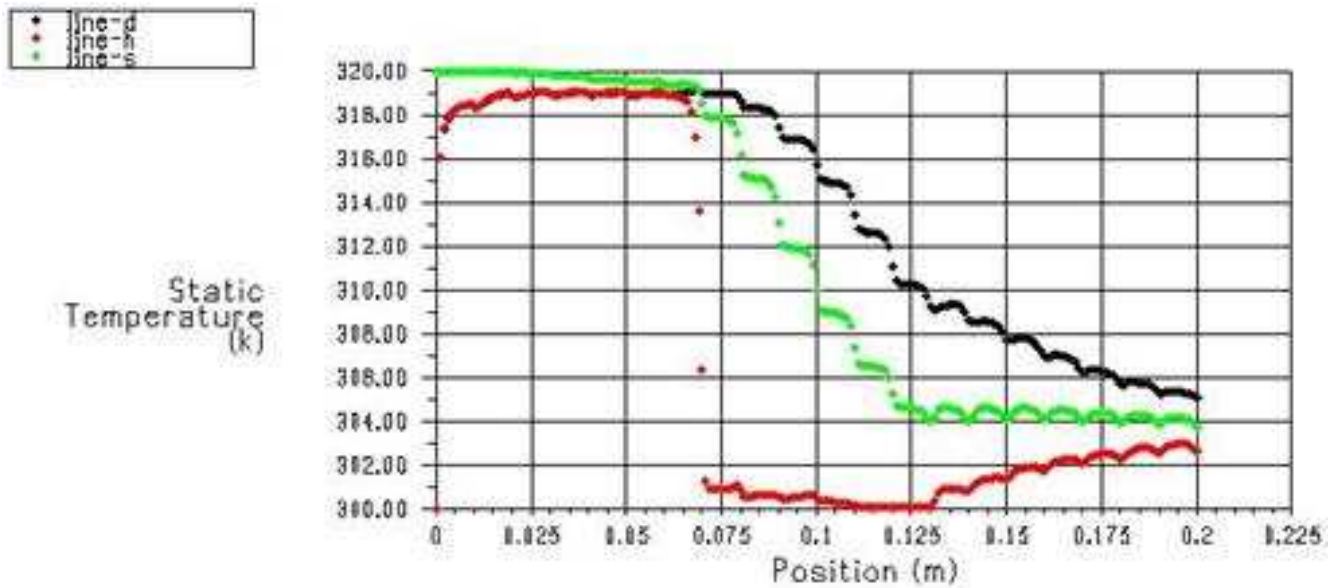


Figure 13. Temperature profiles.

## 2.7. Remarks

As to the blowing air, the simply solution is the air from the production hall. If it is not enough, it should be used the air dryer. For instance, standard air drying procedure finishes at the wet point temperature of +3°C (100% rel. humidity and 4,8 g/kg water content) followed by recuperation on +20°C (32% rel. humidity approx.). Such device needs standard cooling circuit with next investment and operational costs. For informative testing, without next investment costs, it could be to use actual sources of compressed (and dried) air, actually installed in the production hall.

Coiled fleece stays some time in the production hall, where are some standard hydrothermal conditions, for instance point 1 in the Figure 1. It is not good to dry over the fleece, because during next treatment the over dried fleece could be

moisten back. Therefore the proposed final drying should be installed just before packing in the foil. In such case the temperature and humidity of the air inside the fleece volume will be adequate to the air parameters used for final drying. Those parameters define the condition, when the condensation under packing foil arises – it is not possible to prevent it absolutely, but to suppress, only.

Wet air, blown out from the fleece volume, remains in the production hall. It is supposed, that a complete HVAC circuit will not be installed and operated. It would be necessary, it is proposed to install an additional air dryer, only, for reasonable air redrying.

Air filtration – in general, for textile plants it is recommended any standard air filtration to preserve a suitable level of dustiness.

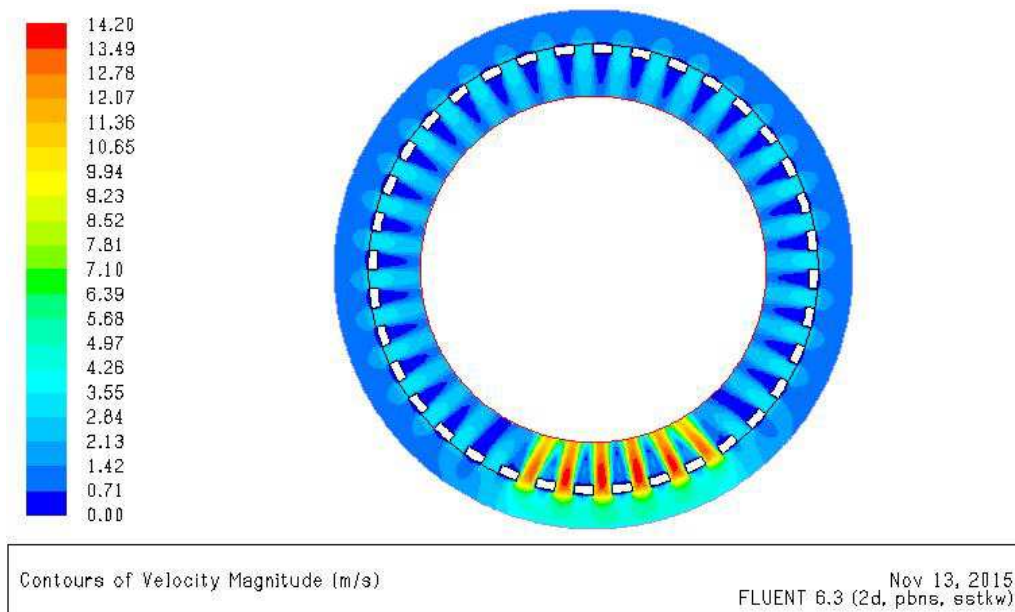


Figure 14. Velocity field – lower part of the drum is open.

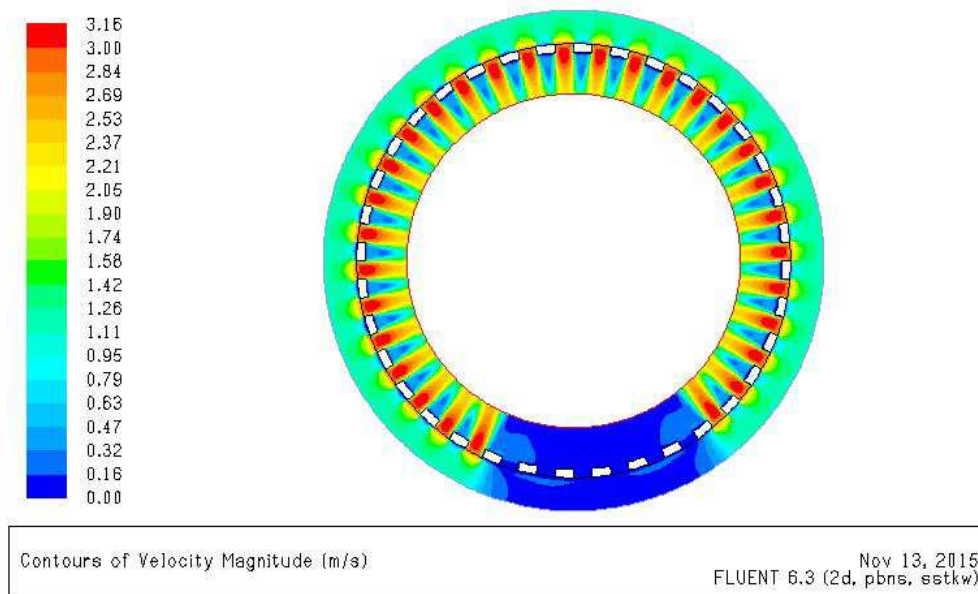
### 3. Drying Drum

The used dryer is designed as perforated drum of large diameter with two supporting cylinders (inlet and outlet), situated in tempered chamber. From the drum inner side is exhausted out the circulating air, at the outside the wet air is going in, replaced by fresh air from the surrounding (hall). The heater keeps the air inlet temperature at 70-80°C. The scheme of the drying process see the Figure 1. The real warming and drying of the treated nonwoven is proceeding in principle by this manner. Simulated case is presented as an illustration, only, the solution of dryer is not the aim of this study.

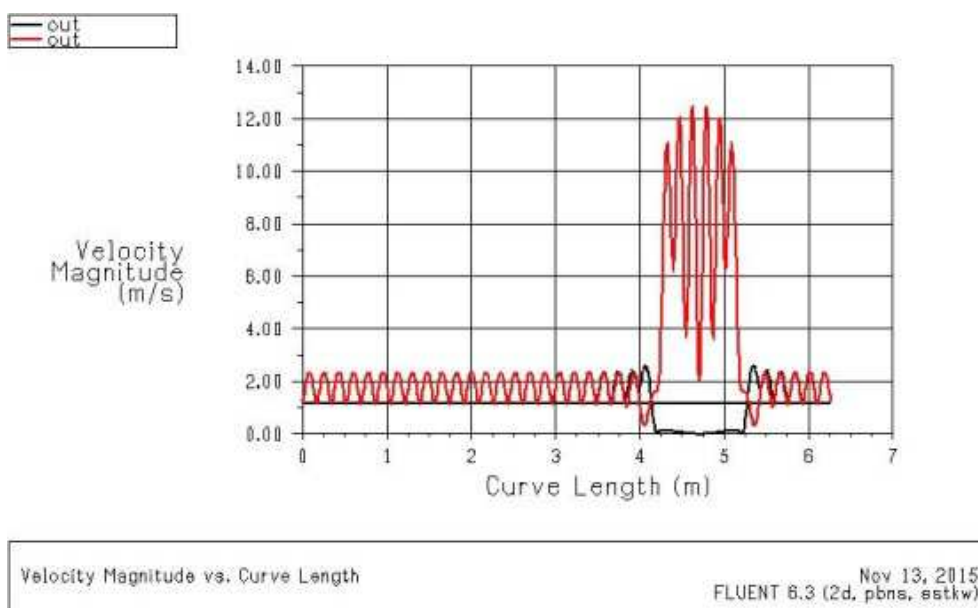
#### 3.1. Passage of the Drying Air Through Dried Layer

Simple planar model contains perforated drum, the rate of perforations is 1:1. From the outside there is completed by surroundings (larger diameter), inside there is added suction (smaller diameter), defined pressure difference of 100 Pa. The perforations on the 5/6 of drum perimeter are covered by permeable nonwoven, except the lower 1/6 - those lower perforations are solved as fully open or fully shut. The permeability parameters see the Par. 2.4.

Resulting velocity field of both cases is presented on the Figure 14 and Figure 15, common velocity profiles are on the Figure 16. The velocity in perforations overlaid by nonwoven is similar in both cases, but at open lower perforations the velocity is of 77% higher. It is a loss of energy, only, without drying effect.



**Figure 15.** Velocity field – lower part of the drum is covered.



**Figure 16.** Common velocity profiles along perimeter of perforated drum (lower perforations are open = picks, covered = low).

The presented results are valid for so-called “hard source”, where the pressure difference is independent on the flow. Really, each fan has any own resistance (operational) characteristic  $\Delta p$  (Pa) =  $f(V \text{ (m}^3/\text{s)})$  and real operating state of the system fan + drum should be find out by iterative method, using this characteristic, [10] etc.

### 3.2. Contact Warming

From the strength reasons the perforations are manufactured on some part of the whole surface, only, therefore on the significant part of the fleece surface is not any air blowing through, but warming by contact manner. This model of

contact warming is starting from the previous model of air suction. To shorten the solution time, one perforation is here solved, only, with adjacent part of drum and periodic boundary conditions. The curvature of large drum diameter is neglected. The suction is defined as -1 kPa at the outlet side. The simple geometry is evident from following results.

The model area is at first moved with peripheral velocity of 16 m/s, followed by unsteady solution with defined temperatures 300 K (27°C) in the nonwoven volume and 350 K (77°C) in the volume of drum and drying chamber. Next Figures 17 to 20 present the situation at the time of 10 s from the start.

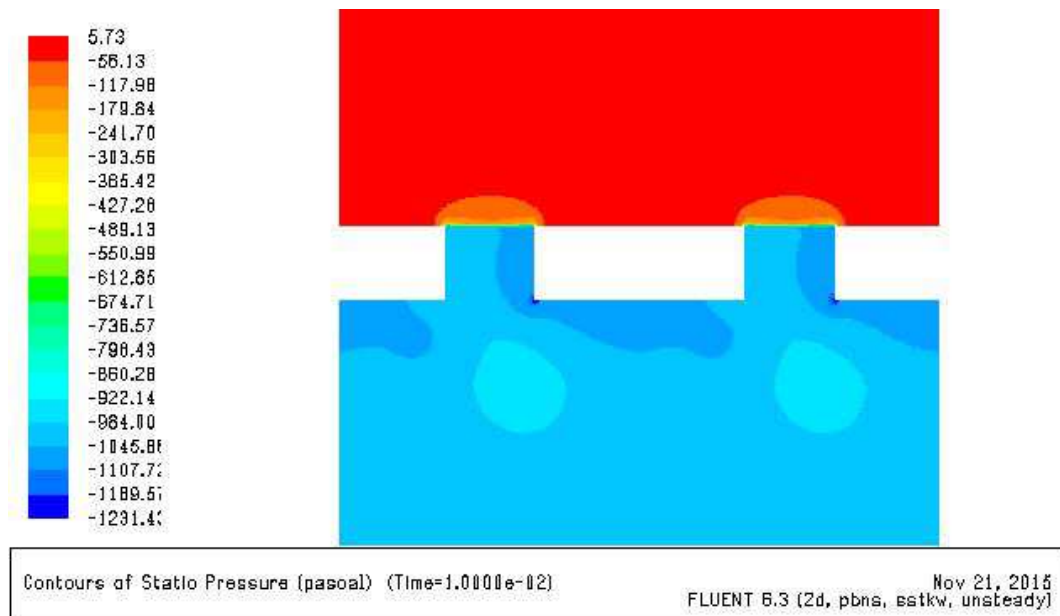


Figure 17. Pressure field.

In the fleece layer of defined permeability is the sudden pressure decreasing, so-called “porous jump”.

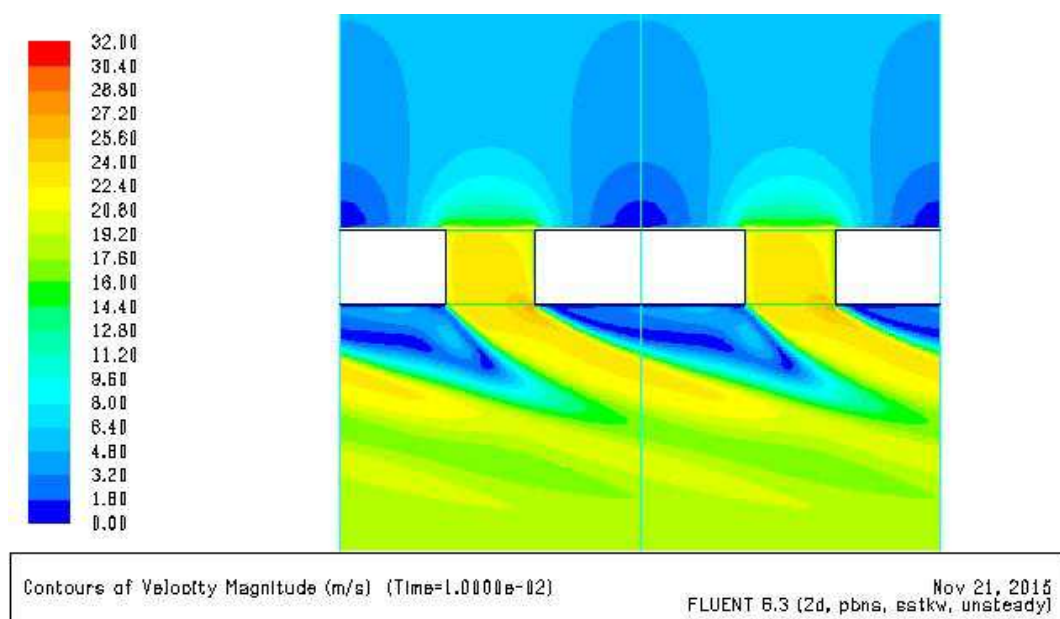
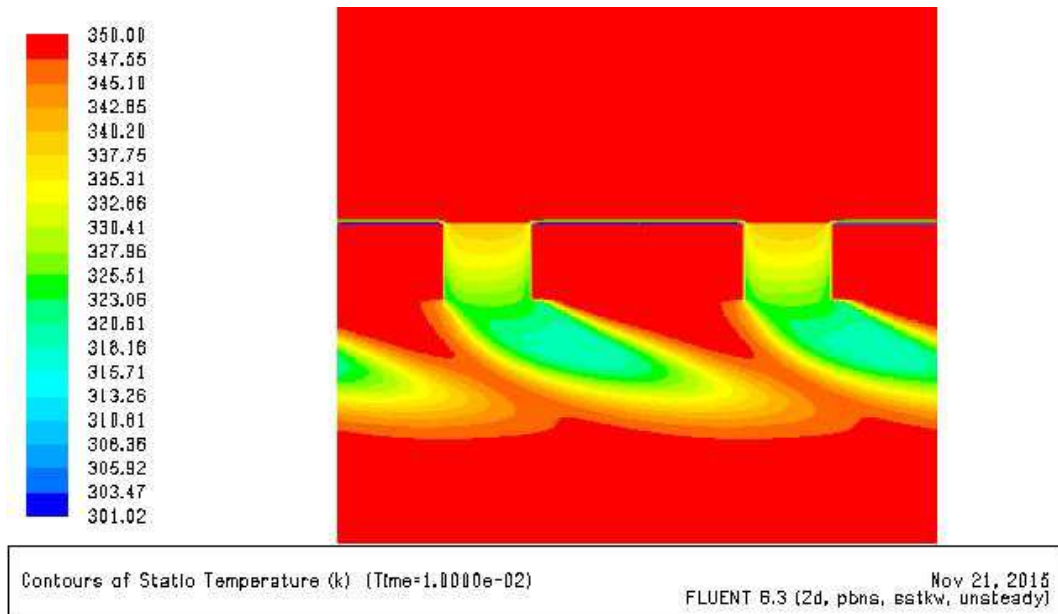


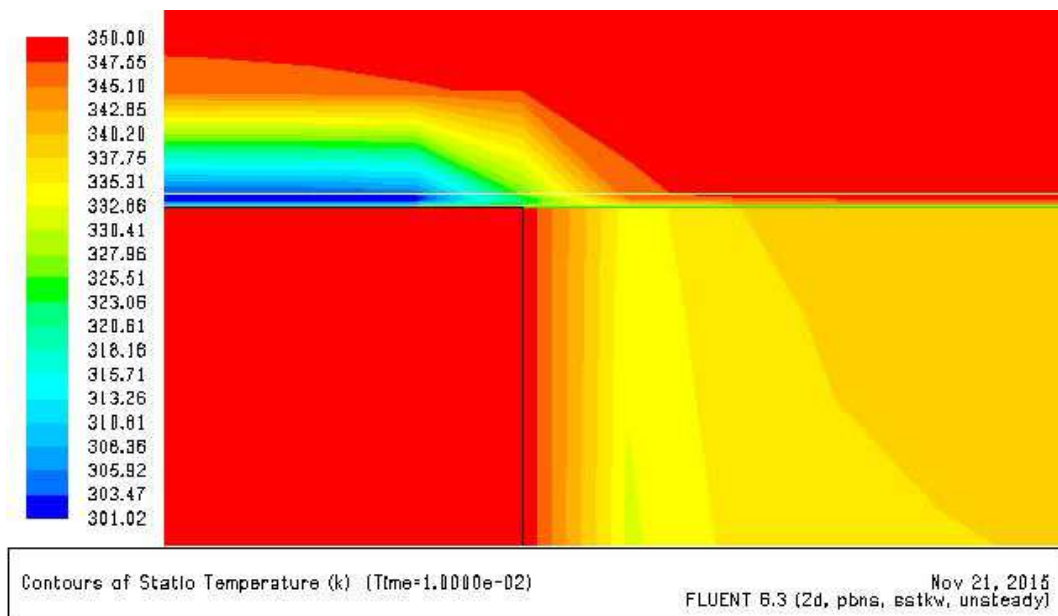
Figure 18. Velocity field.

The velocity field is created from the given pressure difference, the flow direction under the drum wall is given as vector sum of the drum rotation (16 m/s to right) and of the inlet velocity into the perforation in the drum wall (theoretical maximum of 21,9 m/s down), the resulting deflection of 54° from the perforation axis.



**Figure 19.** Temperature field.

The cold air (and evaporated humidity) in the volume of blown fleece is going down and gradually is mixed with warm volume of drying chamber.



**Figure 20.** Detail of the temperature field.

The detail of the temperature field shows that by blowing over the perforation (right side) the fleece is effectively warmed, but by the contact warming (left side) the warming is low – the very airy fleece is a good thermal insulation.

The Figure 21 presents temperature profiles in the fleece thickness ( $h - s - d$  = upper - middle - lower level) in the time of 10 ms after the start of the simulation present that the fleece warming in the contact with drum is few effective, the

cross blowing is much more effective.

### 3.3. Conclusion

From the preliminary numerical simulation of the process on the perforated drying drum arises that the main part of the fleece warming is arising by the cross blowing of the drying air through the fleece thickness. The contact warming by



drum surface is low, the airy fleece is acting as thermal insulation. Some areas on the fleece surface are well and quickly dried (areas of perforations) and the others are not well and slowly dried (areas of the drum wall).

For next progress it is important next conclusion: for quick, reliable and effective substitution of warm and wet air in the nonwoven volume it is important to use the cross blowing by more cold and more dry air, probably sufficient this from the surroundings.

Remark: for solution of drying dynamics should be known the so-called drying curves, i.e. the time-dependent reduction of the nonwoven mass (= humidity loss) in dependence on tested material (mass per square unit, porosity, production velocity etc.) and on drying conditions (air temperature, velocity, humidity, flow direction etc.). Typical illustration is mentioned in any text-book of drying [11] etc., see the Figure 22, real values are not available.

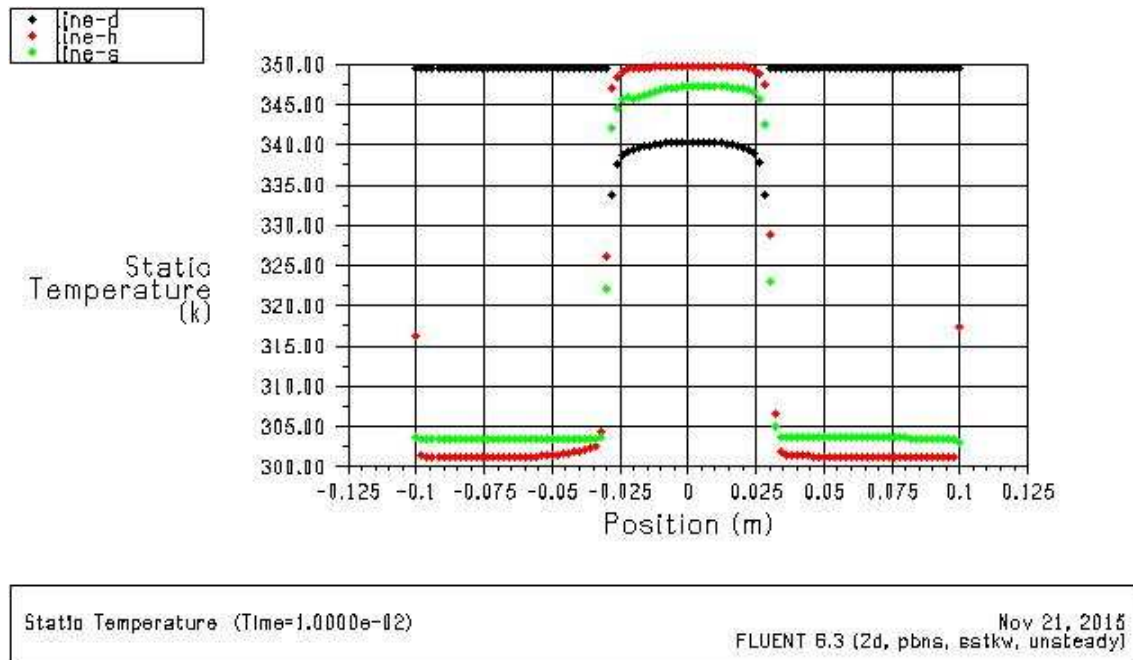


Figure 21. Temperature profiles in the nonwoven thickness.

## 4. Final Drying of the Fleece Layer

From many tested cases here is presented only one complex case.

### 4.1. Two-Phases Model

In preliminary cases (chapter 2 and 3) the temperature of fleece layer was determined as criterion of filling its volume by cross blown cold air. It was assumed that when the temperature of the fleece volume is decreasing on the surrounding temperature, then the warm air in the fleece volume is fully exchanged by the cold one. But such procedure does not include the thermal capacity of fleece yarn material, even if they represent 20% of the free (not pressed) volume, only. The vapour heat is not included, too, calculations were made for dry air, only.

So it is better the two-phases model, containing the water vapour. The hypothesis is tested here on the same model, which is presented in the chapter 2.6. From many created and tested cases the one nozzle of air pressure 1 kPa for fleece velocity of 10 m/s was used.

Water contents were used after the Figure 1: in the fleece volume there is  $x = 0.023$  kg/kg (point 5), for surroundings and nozzle there is  $x = 0.007$  kg/kg (exact values are 0.02248

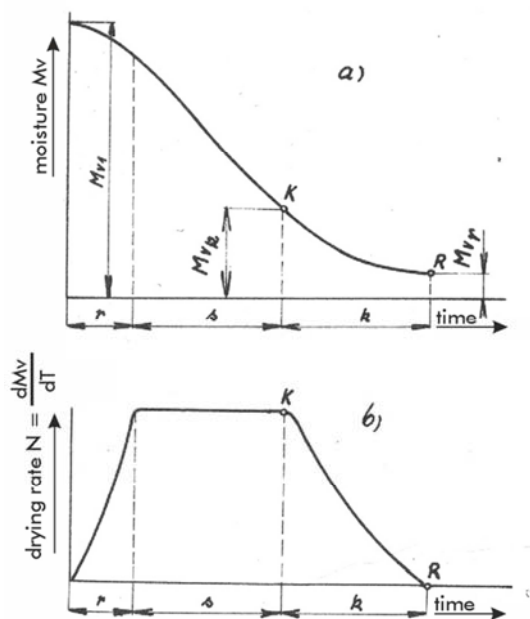


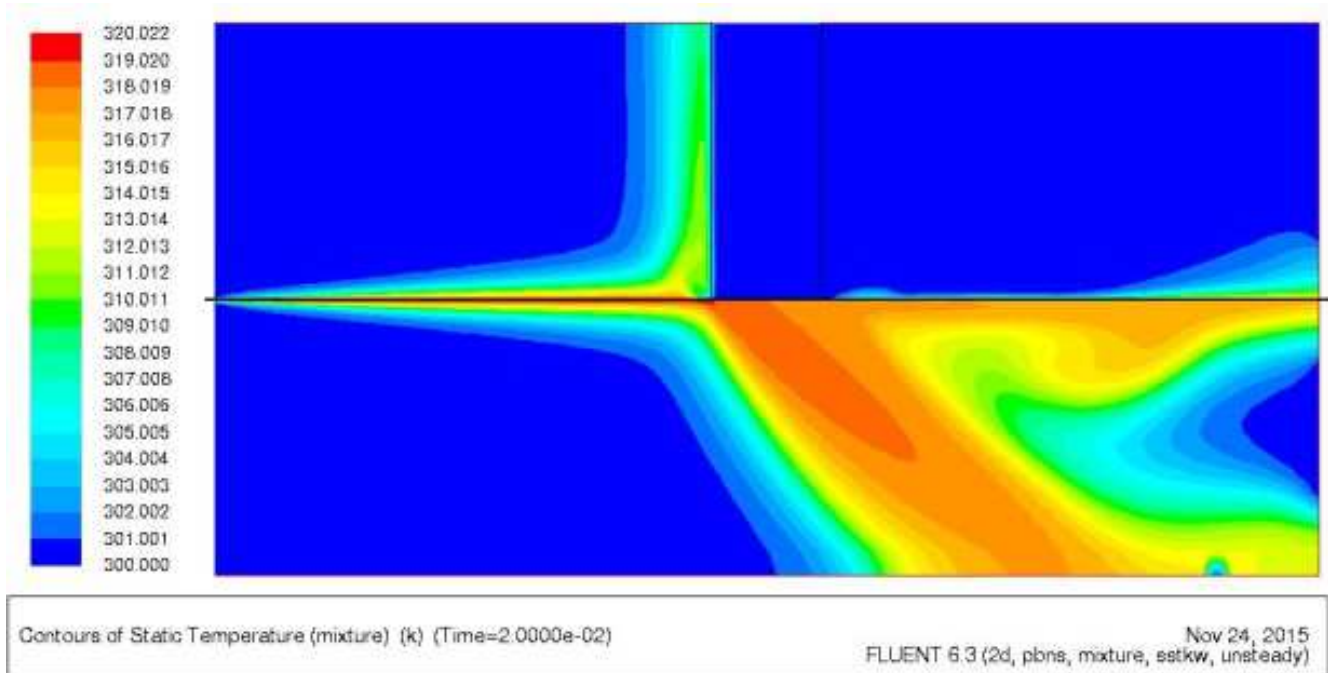
Figure 22. Typical mass (humidity) decreasing in time and drying velocity.



resp. 0.00695 kg/kg, differences are neglected).

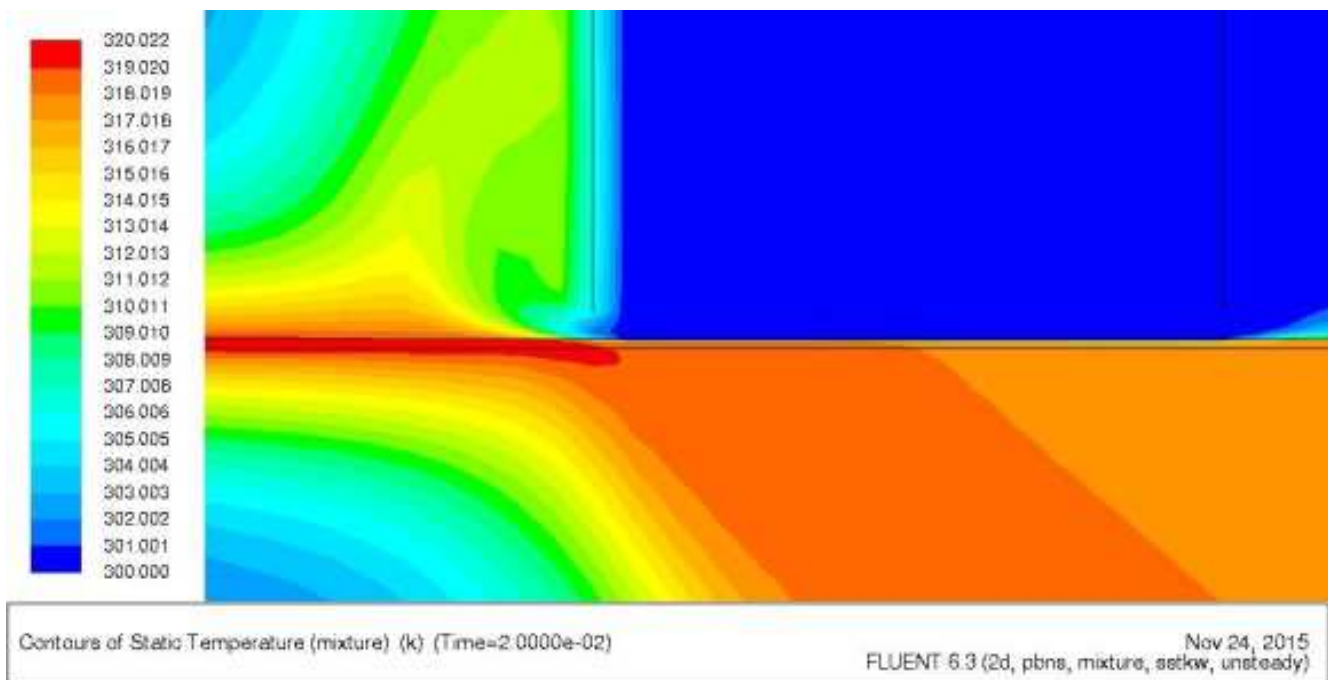
are presented on the Figures 23 to 25.

As an illustration of results typical flow fields and profiles



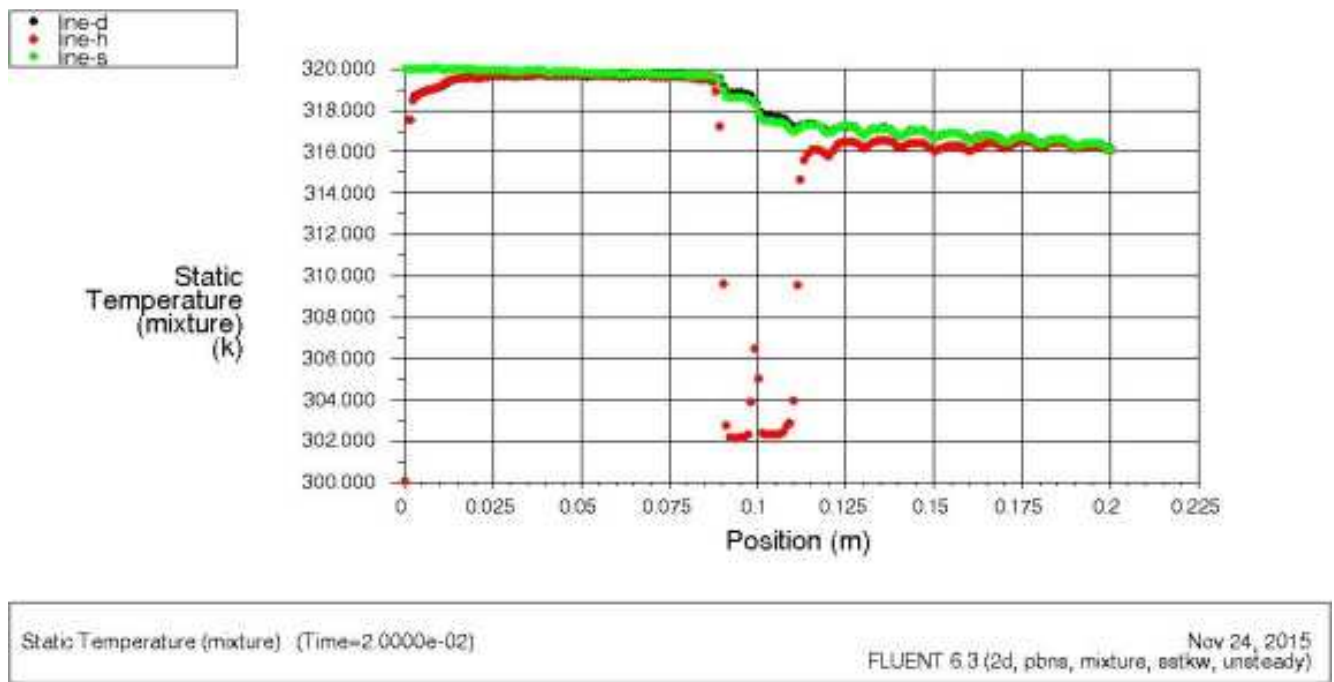
**Figure 24.** Temperature field.

The image is analogous with the one-phase model of dry air.



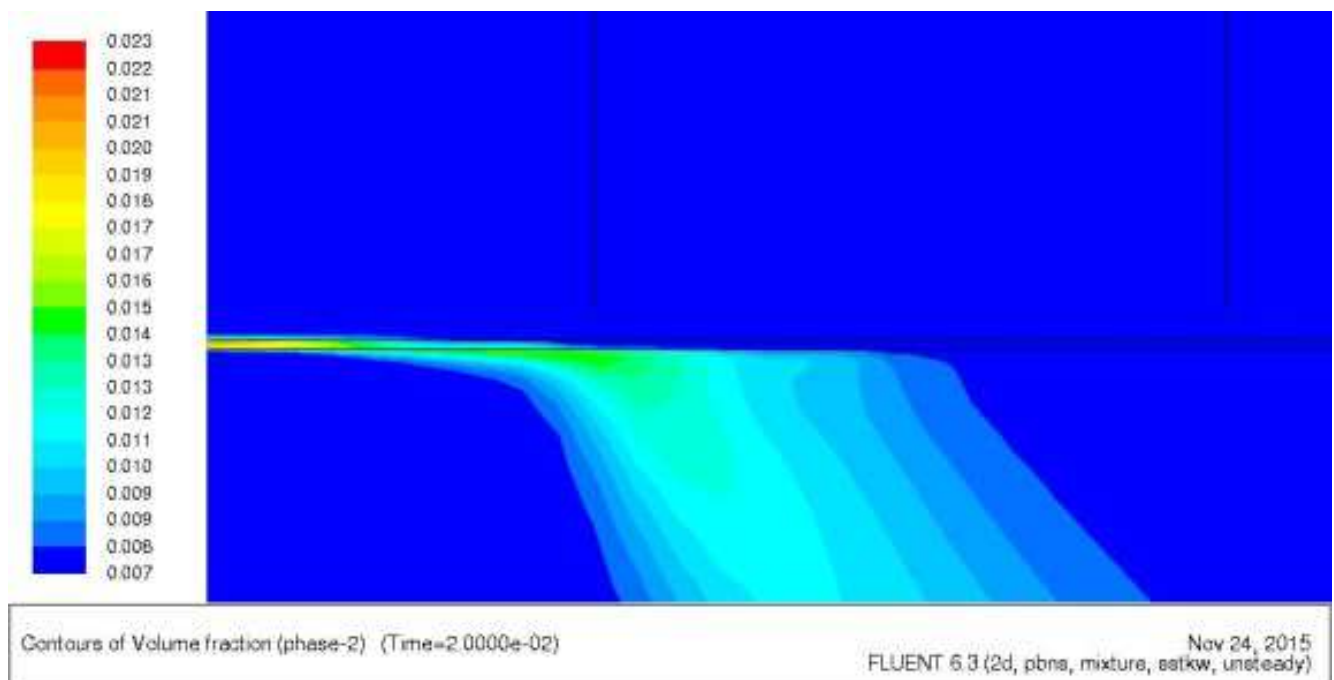
**Figure 25.** Typical mass (humidity) decreasing in time and drying velocity.

The detail of the previous temperature field in the vicinity of nozzle orifice shows that the fleece is cooled, but not on the temperature of the crosswise blown air.



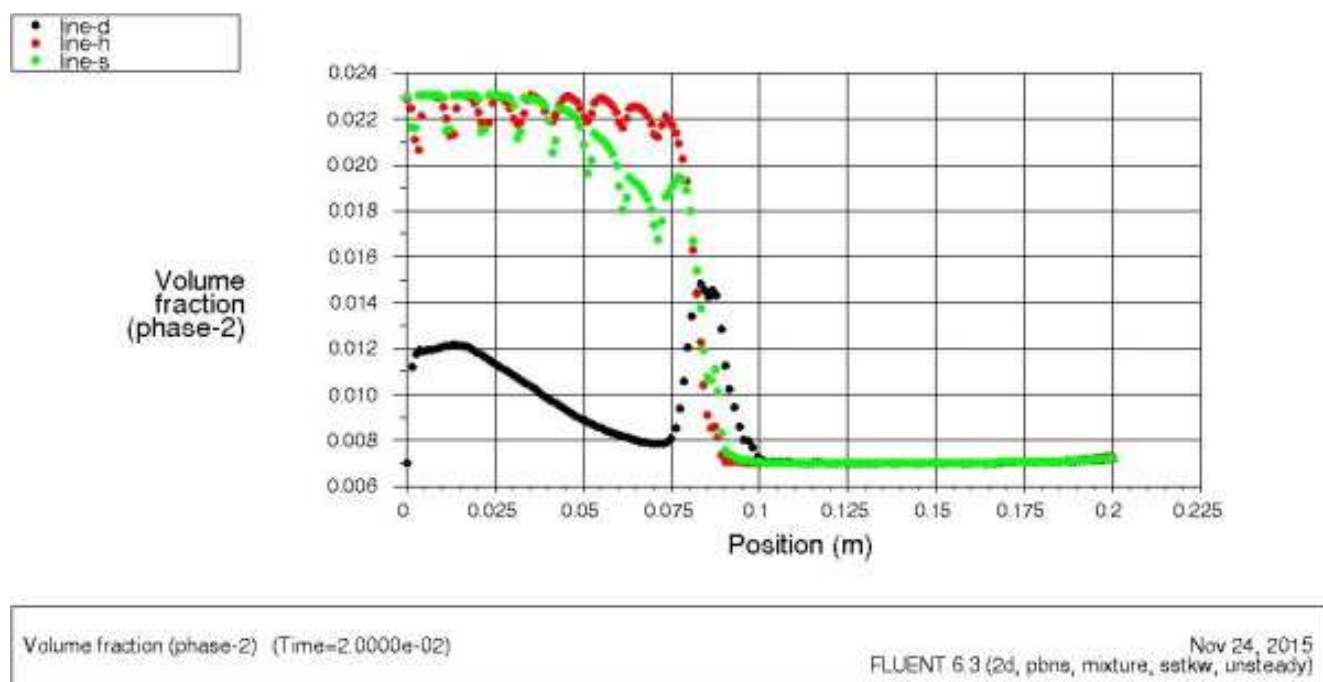
**Figure 26.** Temperature profiles in the fleece volume.

Comparing with the one-phase model of dry air (Figure 10 and Figure 13), the graph on the Figure 26 shows that the fleece cooling under nozzle is lower, but after the nozzle the temperature is not increasing – probably the effect of added vapour.



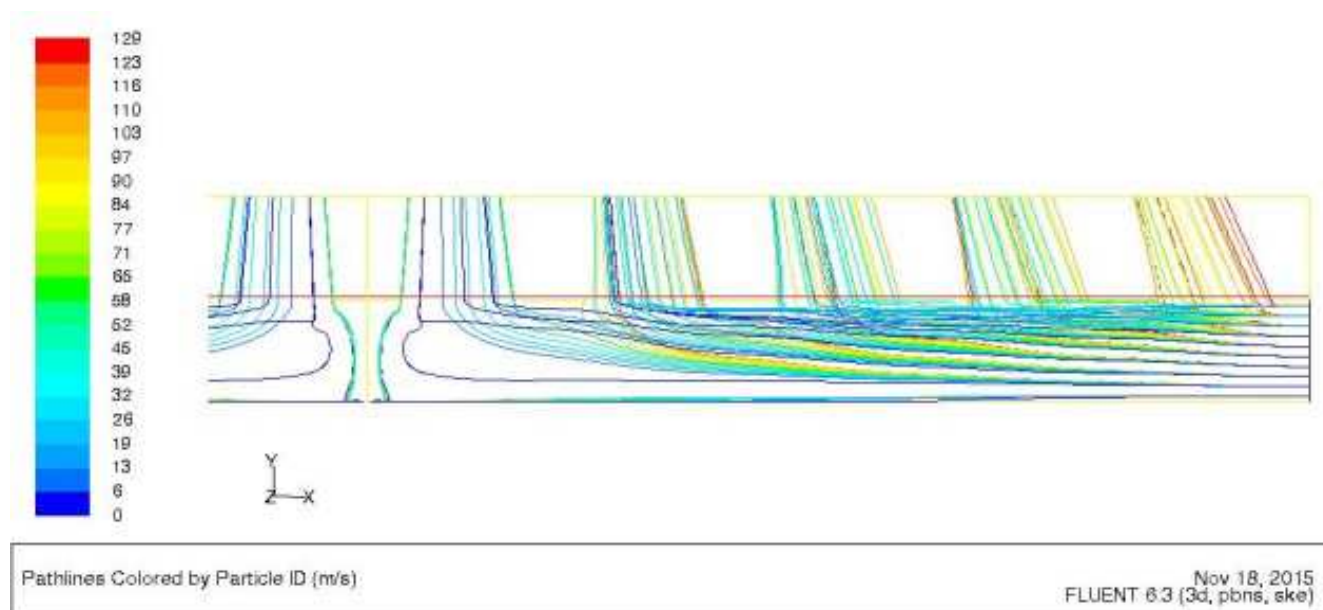
**Figure 27.** Detail of humidity fraction.

The Figure 27 shows that for given parameters of the solution (nozzle dimensions, air pressure, fleece velocity) the air in the fleece volume is fully exchanged in the one half of the nozzle orifice width.



**Figure 28.** Humidity profile in the fleece volume.

The Figure 28 presents the air humidity in the fleece volume - blowing the surrounding air through the fleece thickness the initial water content of 0.023 kg/kg is decreasing onto the humidity of surrounding air of 0.007 kg/kg.



**Figure 29.** Streamlines.

After the Figure 29 in the symmetrical half of the common inlet remains some flow inequality.

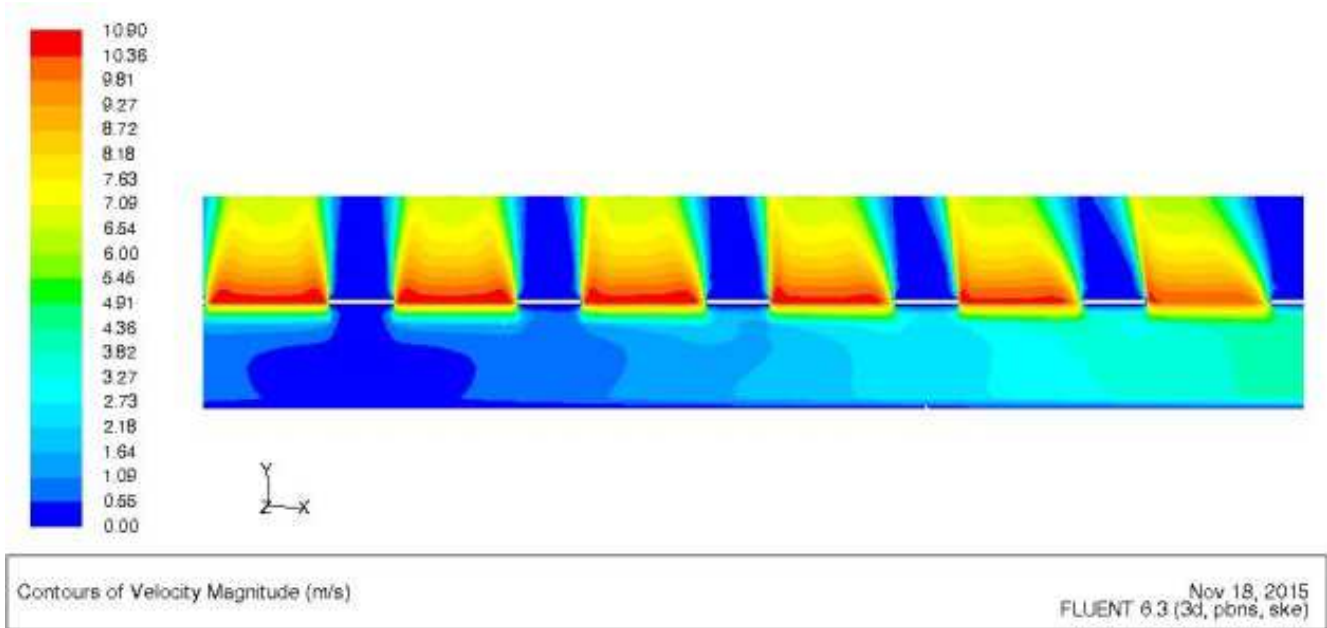


Figure 30. Velocity field.

Figure 30 presents another view on the same situation.

#### 4.2. Inlet of Blowing Air

To be sure, that the drying effect along the whole nozzle length will be the same, the air flow along must be the same, too. It is fulfilled, when the cross section of the common inlet is large enough, to get constant pressure value in the whole

common volume – as a pressure vessel. Then it is not necessary to insert any directional partitions.

Inlet pressure for this simulation is defined as 1 kPa. The result shows that for the rate of cross sections inlet/outlet = 2/1 remains some small inequality between the middle and outer part of the nozzle length, in the range -7% to +4% of the ideal value.

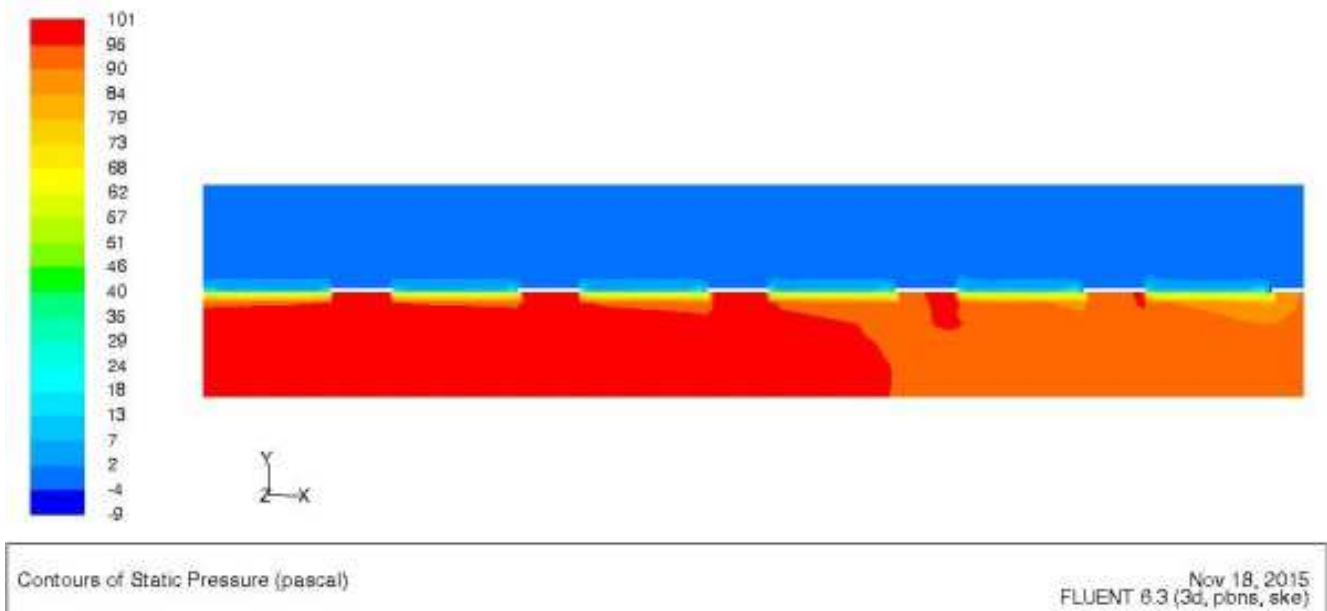


Figure 31. Pressure field.

Figure 31. presents the pressure field of the same case - in the inlet part (bottom) there is visible quite uniform pressure value, in the middle part of the nozzle (left) the pressure is slightly higher.

## 5. Conclusion

Detailed conclusions are presented in individual chapters above. The short summary follows:

- 1) The original task “to reduce the temperature of

produced fleece” should be changed on “to reduce the water content in the air contained in the treated fleece layer”, because the cooling of the fleece does not eliminate the problem.

2) The simple model of one-phase dry air, only, uses as criterion of well blown fleece volume by cross flow the fact that inner temperature of the fleece is identical with temperature of the cross flow. The method gives a quick overview of various design parameters, influencing the drying process, but without the influence of mass specific heats of water vapor and yarns.

3) The two-phase model is more complicated, but more suitable for the assessment, how the wet air in the fleece volume is exchanged by cross blowing dry air from the surroundings. As the first information about the influence of nozzle number and layout the previous model of dry air sub 2) is sufficient, with observing of temperature changes, but with regard to the thermal capacity of yarns in the fleece volume the total cooling is slow. The two-phase model with water vapor describes exactly the actual situation of wet air parameters during its blowing through the fleece.

4) Simple checking simulation of inlet part of blown air confirms proper dimensioning of flowed cross sections. The cross section of the common inlet chamber should be as minimum twice larger than the sum of individual outlet cross sections. The criterion is fulfilled, the individual flows are well balanced.

5) The efficiency of the actually used design of drum drier is not optimal. The lower sixth part approx. of the drum is not covered by treated layer and so a significant air volume is blowing through without any drying effect. And more, instead of the efficient blowing of dry and cold air through the treated layer, the most part of drying process is realized by contact heating (like ironing), not so efficient. But it should be said, that the reason is here the strength and stiffness of long and perforated drum of large diameter.

6) The proposed solution is resulting from well-known principal laws of physics, or of fluid mechanics and thermo-mechanics respectively. They are permanently valid till today and it is not necessary to reference any next citations from the last period, because they contain the same matter.

Of course it is a pity that they are not applied thoroughly and carefully in the daily practice of a plant. For instance, the factory producing over 50 millions  $m^2$  of the fleece per day has operational problems as presented above.. Any improvement of the product quality increases the profit.

7) Used method of flow numerical simulation gives

relative simple, quick and realistic idea about the solved problem and about possible improvement of its efficiency, performance etc. Suitable results, only, should be verified by experiment, because any model is an approach to the reality, only.

## Acknowledgements

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