How to cite: Doğu, D. & V. Demir, 2025. Investigation of pressure drop in main air line of pipeline milking system. Ege Univ. Ziraat Fak. Derg., 62 (1): 49-62, https://doi.org/10.20289/zfdergi.1514376

Research Article
(Araştırma Makalesi)

Ege Üniv. Ziraat Fak. Derg., 2025, 62 (1):49-62
https://doi.org/10.20289/zfdergi.1514376

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Investigation of pressure drop in main air line of pipeline milking system*

Süt borulu sağım sistemi ana vakum hattında basınç kayıplarının incelenmesi

* This article has been summarized from Damla DOĞU's MSc thesis. This thesis was carried out in the Agricultural Engineering and Technologies, Graduate School of Natural and Applied Sciences, Ege University.

Received (Alınış): **11.07.2024** **Accepted** (Kabul Tarihi):**05.10.2024**

Keywords: CFD, friction loss, pressure loss, vacuum drop

Anahtar sözcükler: HAD, sürtünme kaybı, basınç kaybı, vakum düşüşü

ABSTRACT

Objective: The objective of the study is to investigate the pressure drop analytically, numerically and experimentally in the main air line of the pipeline milking system.

Material and Methods: The study was carried out in a pipeline milking system, where the main air line consists of a galvanized straight pipe nominally 50 mm in diameter, with one bend. The pressure drops in the pipeline were measured experimentally at different flow rates. In addition, the pressure drops calculated using theoretical equations and determined using various turbulence models with the Computational Fluid Dynamics (CFD).

Results: During the experiments, a pressure drop of 0.65 kPa was measured at high flow rates. It was found that the results calculated using the theoretical equations were very close to the experimental data. The lowest MAE and NRMSD values for pressure drops calculated with different CFD turbulence models were found in the Realizable k-ε model.

Conclusion: The results showed that the pressure drops in the main air line could be calculated with minor errors by using the numerical analysis method and the Realizable k-ε turbulence model.

ÖZ

Amaç: Çalışmada, süt borulu sağım sisteminin ana vakum hattında oluşan basınç kayıplarının deneysel, analitik ve sayısal olarak incelenmesi amaçlanmıştır.

Materyal ve Yöntem: Çalışmada bir süt borulu sağım sisteminin ana vakum hattı dikkate alınmıştır. Ana vakum hattı, 50 mm anma çaplı galvaniz düz boru ve dirsekten oluşmuştur. Hattaki basınç kayıpları farklı debi değerlerinde deneysel olarak belirlenmiştir. Ayrıca basınç kayıpları, çeşitli kaynaklarda verilen analitik eşitlikler yardımıyla hesaplanmış ve Hesaplamalı Akışkanlar Dinamiği (CFD) analiz yöntemiyle farklı türbülans modelleri kullanılarak belirlenmiştir.

Araştırma Bulguları: Denemelerde yüksek debi değerlerinde basınç kaybı değeri 0.65 kPa ölçülmüştür. Analitik eşitlikler ile hesaplanan sonuçlar deneysel verilere oldukça yakın bulunmuştur. Ana vakum hattında deneysel olarak ölçülen ve farklı türbülans modelleri ile hesaplanan basınç kayıpları istatistiksel açıdan değerlendirildiğinde, en düşük MAE ve NRMSD değerleri Realizable k-ε modelinde bulunmuştur.

Sonuç: Ana vakum hattındaki basınç kayıplarının Realizable k-ε türbülans modeli kullanılarak çok düşük hata ile tahmin edilebileceği ve sistem tasarımında kullanılmasının uygun olacağı söylenebilir.

INTRODUCTION

Milk is a basic source of nutrients for the human body. It contains protein, fat, carbohydrates, all vitamins and minerals. The consumption of milk and foods made from milk leads to an increase in the number of dairy farms (Kuraloğlu, 1998; Özdemir et al., 2000; Üçer, 2008). Milking is the periodic removal of the milk produced in the animal's udder. Milking can be done manually or by machine, depending on the size of the dairy farms.

Milking machines are used extensively in intensive dairy farming. The mechanization and automation of milking is achieved with these machines. On the other hand, the milking is done hygienically and the milk yield increases (Gürhan & Çetin, 1998). Milking machines are in direct contact with the animal. Therefore, the performance of the machine has a direct impact on milking success (Öz & Bilgen, 2002).

Milking systems can be classified according to the location of their functional components and how the milk is collected: portable (bucket) milking systems, fixed (pipeline) milking systems and automatic (robotic) milking systems.

Pipeline milking systems consist of two sections. The first section is the milking parlour. This section consists of the main air line and the pulsators. The pulsators are connected to each milking cluster. They provide the milking by transferring vacuum and atmospheric pressure to the teats. The pumped milk mixes with air. It is then transported through short milk hoses into the milk line. The milk line ends at the receiver, where the pumped milk is collected. The second section consists of the main air line between the receiver and the vacuum pump. The main air line distributes the air to the various parts of the vacuum system: sanitary trap, vacuum meter, regulator, vacuum tank and vacuum pump.

The main air line can be made of glass, plastic, galvanized or stainless metal, depending on the requirements of the milking system. The parts of these materials that come into contact with the air should have a smooth structure to avoid any resistance. Pressure drops that occur in straight lines are referred to as "major pressure drops". These pressure drops increase significantly depending on the length of these lines and the velocity of the air. Besides these, fittings (elbows, valves etc.) and pressure measurement points in the main air line cause pressure drops. These losses are referred to as “minor pressure drops”. Minor pressure drops are usually less than the major pressure drops that occur in straight lines. However, if there are many fittings in short pipelines, minor pressure in main air line of the pipeline milking systems can reach larger values than major pressure drops (Daugherty & Franzini, 1965; Cengel & Cimbala, 2006).

The pump capacity must be sufficient for the total number of milking units while operating at a vacuum pressure of 50 kPa, which is suitable for milking cows. This air capacity can vary depending on the design of the milking system. In general, it can range from 70 $Lmin^{-1}$ per unit for systems with 20 units to 85 $Lmin^{-1}$ for smaller systems with 5 units (FAO, 2024).

Spencer (1993) presented pressure drop tables for pipe sizing in the main air lines of milking systems. It is also stated that the pressure drop value in the air line should be between 0.85 and 1.7 kPa and should not exceed 2.5 kPa. Reinemann (2019) states that the pressure drop in the main air line between the vacuum pump and the milk tank should not exceed 2 kPa. Berry et al. (2005) stated that according to the ISO 5707E standard, the pressure drop in the main air line should not exceed 5% of the pump capacity. Clarke (1983) compared incompressible, isothermal and adiabatic flow equations that can be used to calculate pressure drops in main air lines of pipeline milking systems at air flow rates of 30, 50 and 70 Ls^{-1}. The comparison showed that there is no significant difference between the three methods and that the flow can be assumed to be incompressible and the Darcy-Weisbach equation can simply be used. The study also measured the pressure drops over a test length of 10 m using two different stainless steel pipes of 28 and 48 mm inner diameter and showed that the results are compatible with the Darcy-Weisbach equation.

A main air line should be designed for each milking plant and a system should be installed depending on the characteristics of the plant. This line should be sized to minimize the pressure drop. There are limited scientific studies on pressure drops in the main air lines of milking systems (Clarke, 1983; Spencer, 1993; Reinemann, 2019; Berry et al., 2005). Standards and recommendations generally state that pressure losses should not exceed acceptable limits when dimensioning pipelines (Tan et al., 1993). Thus, energy efficiency and cost reduction are achieved by selecting the appropriate line design and vacuum pump.

The inner diameter of the main air lines should be dimensioned so that the milking process is not affected by vacuum drop. If the milking system is tested according to the ANSI/ASABE standard, the vacuum pressure drop near the receiver and regulator should not exceed 1 kPa. In addition, the vacuum drop between the receiver and the vacuum pump should not exceed 3 kPa for air lines. The internal diameter and slope of the milkline shall be such that the vacuum drop between the receiver and any point in the milkline does not exceed 2 kPa with all units operating at the designed milk flow and airflow (ANSI/ASABE, 2016; ISO, 2007).

In recent years, in addition to experimental investigations, simulation studies using computational fluid dynamics (CFD) have also been carried out on the flow properties and pressure drops along the pipe line. Cürebal (2016) investigated the flow of air, water and natural gas in a 90° elbow with different diameters in various turbulence models. The three-dimensional solution model that comes closest to the experimental results was determined as SST k-ω model. It has been shown that minor pressure drop coefficients in elbows decrease with increasing pipe diameter and flow velocity.

Mossad et al. (2009) carried out a numerical and experimental investigation of turbulent air flow in a sharp 90° elbow. The researchers used Ansys Fluent software for their simulation studies and analyzed three different turbulence models. As a result of the study, it was found that the Realizable k-ε model provided the best results.

The study aimed to investigate analytically, numerically and experimentally the pressure drops in the main air line of the pipeline milking system. In addition, the general aim of the study is to obtain basic data related to engineering calculations for the design and operation of pipeline milking systems.

MATERIALS and METHODS

This research was conducted in the Milking Technologies Laboratory in the Department of Agricultural Engineering and Technologies at the Faculty of Agriculture at Ege University. The pipeline milking system is located at sea level (0-300 m). It consists of a vacuum pump, main vacuum line, regulator, connection point for the milk receiver, and measurement points (Figure 1).

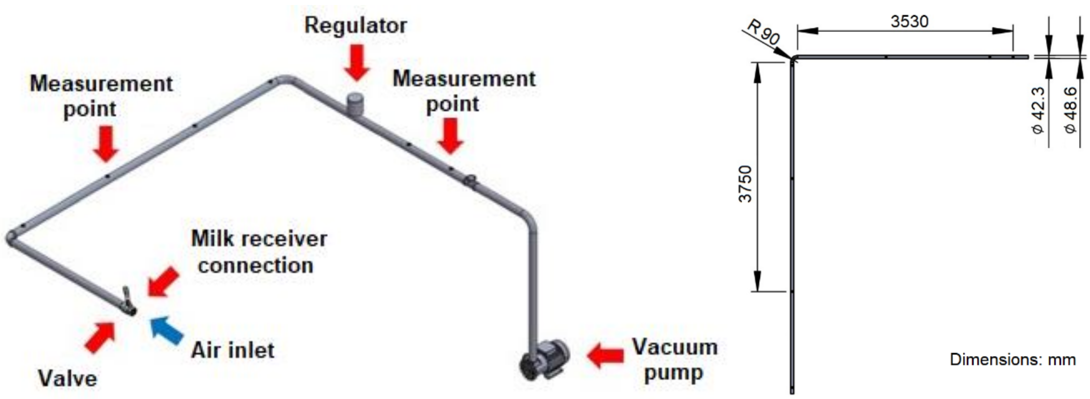

Figure 1. Schematic view of the test stand and the measurement points of the pipeline milking system.

Şekil 1. *Süt borulu deneme düzeninin şematik görünümü ve ölçüm noktaları.*

In the experimental set-up, the main air line consists of a galvanized pipe with a nominal diameter of 50 mm (outer diameter: 48.6 mm, inner diameter: 42.3 mm) (Figure 1). In the connections on the main air line, two long sweep bends and a standard elbow were used. The total straight pipe length between the pressure measurement points is 7.28 m. Air was supplied by a vacuum pump consist of an oil-lubricated multiple-cell rotary vane (Westfalia RPS 400-GEA Farm Technologies GmbH, Germany).

Methods

The study was carried out in three stages: experimental, analytical, and numerical (computational fluid dynamics) analysis.

Experimental studies

The pressure drop between two pressure measurement points in the main air line was measured at different flow rates. The flow rate of the vacuum pump was controlled by the valve. The regulator was deactivated during the experiments. When measuring pressure and air velocity, a distance of at least 5D of the pipe inner diameter from the inlet and/or outlet of the fittings was taken into account to minimize the turbulence effect (Cengel & Cimbala, 2006; Ntengwe et al., 2015; TS, 2019). The air temperature was also measured and recorded during the measurements.

A digital multifunction measuring instrument (Testo 480, Germany) was used to measure air velocity and differential pressure. The air velocity was measured with a digital propeller-type air velocity meter (propeller diameter: 16 mm, measuring range: 0.6-50 ms^{-1}, accuracy ± (0.2 ms^{-1}+1% measured value) (Figure 2). The probe of the air velocity meter was setled at a distance of at least 5D from the main air line. The mass and volume flow rates were calculated by measuring the air velocity in the main air line.

Figure 2. Digital air velocity and differential pressure meter.

***Şekil 2.** Dijital hava hızı ve fark basınç ölçer.*

During the pre-experiments, it was found that the pressure drop values in the vacuum lines were quite low. For this reason, two different methods of differential pressure measurement were considered to ensure the accuracy of the measurement results. The methods used in the experiments were a digital differential pressure meter and a U-tube differential manometer.

Firstly, the pressure drops were measured with a digital differential pressure meter (Testo 480) with an accuracy of ±0.3 Pa+1% measured value and in the range of -100…+100 hPa. The connection between the digital differential pressure meter and the measurement points was made with flexible plastic hoses so that there was no cross-sectional constriction (Figure 2). The device and hoses remained fixed during the experiment.

Secondly, the pressure drops were measured with a U-tube differential manometer, which is made of glass tubes with an inner diameter of 5.3 mm and a length of 500 mm (Figure 3). The U-tube differential manometer is connected to the measuring points with hoses of the same length. Distilled water, and gasoline for more precise measurements were used as liquids in the experiments. The density of distilled water and gasoline was determined using an analytical balance with density measurement function (Precisa XB 220A, 220 g capacity and 0.1 mg sensitivity). The density of distilled water and gasoline was determined to be 0.99676 gcm^{-3} and 0.74180 gcm^{-3}, respectively.

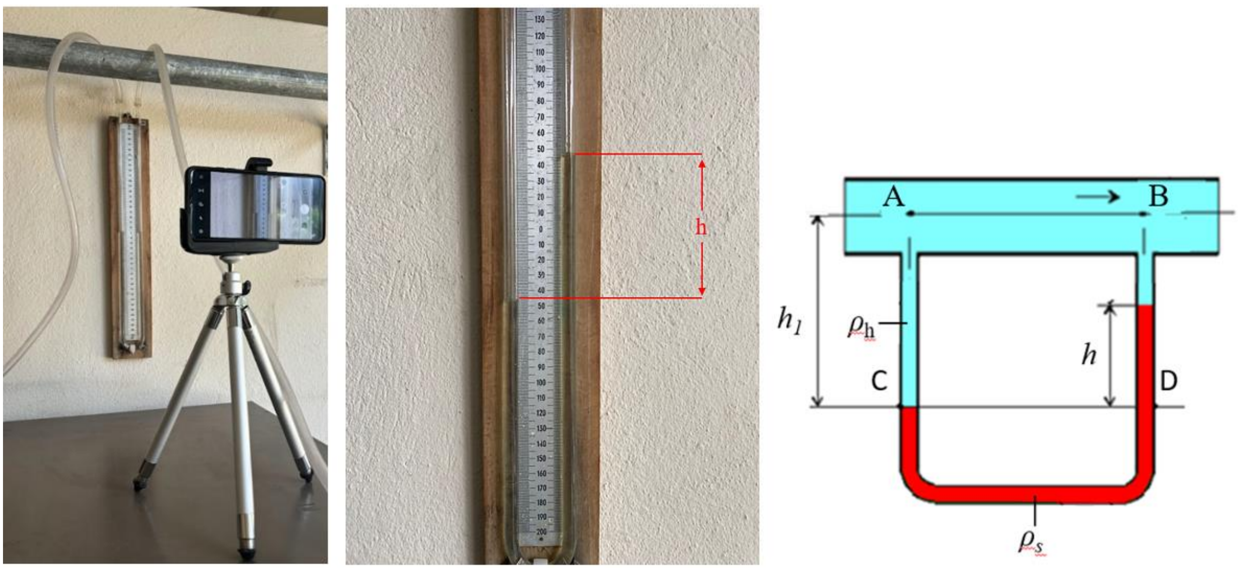

Figure 3. Differential pressure measurement with U-tube manometer.

Şekil 3. *U manometre ile basınç farkı ölçümü.*

The pressure drop in the U-tube differential manometer was calculated as given below.

$$P_c = P_D \rightarrow P_A + \rho_h g h_1 = P_B + \rho_h g (h_1 - h) + \rho_s g h$$

$$P_A - P_B = \rho_h g h_1 - \rho_h g h + \rho_s g h - \rho_h g h_1 \rightarrow P_A - P_B = g h (\rho_s - \rho_h)$$

$$\Delta P = g\, h\, (\rho_s - \rho_h) \tag{1}$$

Where; P_C, pressure at point C; P_D, pressure at point D; P_A, pressure at point A; ρ_h, density of air (kgm^{-3}); P_B, pressure at point B; g, acceleration of gravity (ms^{-2}); h_1, height of pressure at point C (m); h, height of pressure at point D (m); ρ_s, density of measuring liquids (water and gasoline) (kgm^{-3}); ΔP, pressure drop between points A and B (Pa).

The height of the pressure between the measurement points in the main air line was measured with the U-tube differential manometer at different flow rates. During the measurement, the height of the pressure was photographed and recorded. The pressure drop was calculated using equation (1).

Analytical studies

In analytical studies, measured velocity values were used to calculate the pressure drops in the main air line. The method and equations used in the calculations are given below equation (2) was used to calculate the pressure drop (ΔPf) in straight pipes (Clarke, 1983; White, 2001; Munson et al., 2002).

$$\Delta P_f = f\frac{L}{D}\frac{\rho V^2}{2} \tag{2}$$

The Darcy-Weisbach friction factor (f) for fully developed turbulent flow in a straight pipe was calculated using equation (3). The Reynolds number (Re) was determined with equation (4).

$$\frac{1}{\sqrt{f}} = -1.8\,log\left[\frac{6.9}{Re} + \left(\frac{\varepsilon/D}{3.7}\right)^{1.11}\right] \tag{3}$$

$$Re = \frac{VD}{\nu} \tag{4}$$

Where; ΔPf, pressure drop in straight pipe (Pa); V, mean flow velocity (ms^{-1}); D, inner diameter (m); L, pipe length (m); ρ, density of air (kgm^{-3}); f, Darcy-Weisbach friction factor; ε, roughness of inner surface of pipe (m); μ, dynamic viscosity of air ($kgm^{-1}s^{-1}$).

Cengel & Cimbala (2006) stated that the inner surface roughness for galvanized pipes is 0.15 mm. In another study, the inner surface roughness of galvanized pipes varies between 0.07-0.23 mm (Medina et al., 2017). Düz (2017) measured the inner surface roughness of newly produced galvanized pipes and found an average of 0.078 mm. In the analytical calculations and CFD analyzes, the inner surface roughness was assumed to be 0.08 mm.

The minor pressure drop (ΔPk) was calculated using equation (5);

$$\Delta P_k = k\frac{\rho V^2}{2} \tag{5}$$

The total pressure drop in the main air line (ΔP) was calculated using equation (6);

$$\Delta P = \Delta P_f + \Delta P_k \tag{6}$$

The ANSI/ASABE standards state that the pressure drops up to about 3 kPa, in the smooth main air lines can be calculated using equation (7) for plastic and stainless steel installations and equation (8) for galvanized material installations. It has also been shown that a pressure drop of up to around 2 kPa is acceptable (ANSI/ASABE, 2016; ISO, 2007).

$$\Delta P = 27.8\,L\frac{Q^{1.75}}{D^{4.75}} \tag{7}$$

$$\Delta P = 18.74\,L\frac{Q^2}{D^5} \tag{8}$$

Where; ΔP, total pressure drop (kPa); L, pipe length (m); Q, flow rate ($Lmin^{-1}$); D, inner diameter of the pipe (mm).

Numerical analysis (CFD studies)

In the third step of the study, the pressure drops in the main air line of the milking system were investigated by numerical flow analysis using ANSYS Fluent 17.2 software (ANSYS, 2016). The geometric model of the main air line was created and the mesh structure was prepared using ANSYS Meshing software (Figure 4). A tetrahedral mesh structure was used for the analyses. The maximum dimension of a grid in the mesh was set to 1 mm in the bend section and 3 mm in the pipe section. The number of nodes and elements in the mesh structure was more than 8.4×10^5 and 4.4×10^6, respectively.

The analyses were initially performed in different iterations and the number of iterations was set to 500 for optimal convergence.

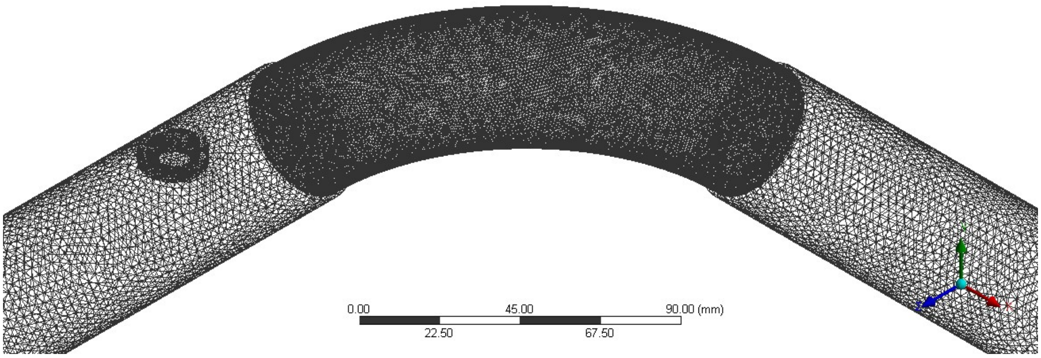

Figure 4. Geometry and mesh structure of the water flow zone in the long sweep bend and the straight pipe section.

Şekil 4. *Dirsek ve düz boru bölümünde oluşturulan ağ yapısı.*

The models listed below were considered to determine the CFD turbulence models that best predict the pressure drop.

-Spalart-Allmaras (Vorticity-Based, Curvature Correction)

-Standard k-ε (Standard Wall and Curvature Correction)

-Realizable k-ε (Standard Wall and Curvature Correction)

-Standard k-ω (Low-Re Corrections, Curvature Correction, Shear Flow Correction)

-SST k-ω (Low-Re Corrections, Curvature Correction, Production Limiter)

The second-order upwind discretization scheme was chosen for momentum, turbulent kinetic energy and turbulence dissipation rate, and the coupled method was chosen for pressure-velocity coupling. Number of the convergence accuracy of the solutions was set to 1×10^{-5}.

The mass flow rate calculated from the measured velocity values was defined as the inlet boundary condition and the outflow as the outlet boundary condition. In the CFD analyses, the density of the air ρ_h=1.178 kgm^{-3} and the dynamic viscosity μ=1.855×10^{-5} kgm^{-1}s^{-1} were used for the ambient temperature 26.5°C measured in the experiments. The experimental and numerical (CFD) pressure drops were compared and statistically evaluated.

Statistical analysis

The mean absolute error (MAE) and normalized root mean square deviation (NRMSD) were considered to compare the differences between the experimental pressure drop data and the values predicted by the CFD models (Willmott & Matsuura 2005; Ding et al 2017). It is known that the lowest values of these comparison criteria from Equations (9) and (10) represent the best model prediction (Willmott et al., 1985; Willmott & Matsuura, 2005).

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|\Delta P_{i,Exp} - \Delta P_{i,CFD}\right| \quad (9)$$

$$NRMSD = \frac{\left[\frac{1}{n}\sum_{i=1}^{n}\left(\Delta P_{i,Exp} - \Delta P_{i,CFD}\right)^{2}\right]^{1/2}}{\left(\Delta P_{i,CFD_{max}} - \Delta P_{i,CFD_{min}}\right)} \quad (10)$$

Where; $\Delta P_{i,Exp}$, experimental pressure drop; $\Delta P_{i,CFD}$, simulation pressure drop values, *n* is the number of data.

RESULTS and DISCUSSION

The results of the measured pressure drops in the main air line of the pipeline milking system are listed in Table 1 and their changes are shown in Figure 5.

Table 1. Measured pressure drops in the main air line of the pipeline milking system

***Çizelge 1**. Süt sağım tesisinin ana vakum hattında deneysel ölçülen basınç kayıpları*

Flow rate	Pressure drop measured with U-tube manometer (distilled water)	Flow rate	Pressure drop measured with U-tube manometer (gasoline)	Flow rate	Pressure drop measured with a digital differential pressure meter
Q (Lmin^{-1})	ΔP (Pa)	Q (Lmin^{-1})	ΔP (Pa)	Q (Lmin^{-1})	ΔP (Pa)
84.3	39	101.2	44	109.6	67.1
261.4	98	185.5	73	236.1	112.3
362.6	137	328.8	131	354.1	151.3
438.5	166	430.0	167	455.3	180.5
615.5	234	531.2	203	497.5	203.3
750.4	293	624.0	232	632.4	250.2
843.2	332	733.6	269	733.6	292.8
952.8	381	860.0	320	860.0	344.4
1079.3	439	995.0	378	978.1	394.7
1197.3	498	1121.4	436	1205.8	497.6
1273.2	537	1247.9	501	1264.8	531.5
1357.5	576	1408.1	581	1340.7	555.8
1399.7	596	1467.1	618	1391.3	574.4
1450.3	635	1509.3	654	1450.3	613.8
1534.6	693	1551.5	683	1559.9	662.0

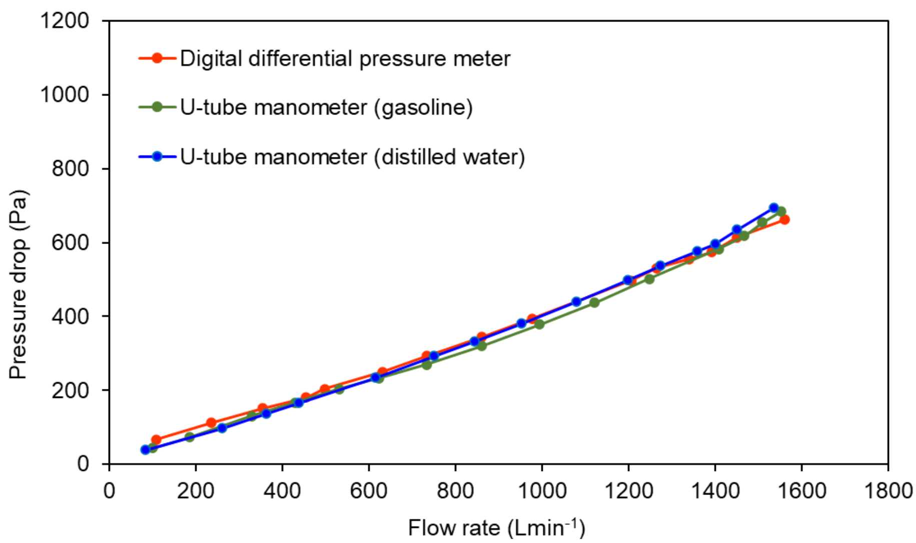

Figure 5. Comparison of pressure drops measured with a digital differential pressure meter and U-tube manometer in the main air line of the pipeline milking system.

***Şekil 5.** Süt sağım tesisinin ana vakum hattında dijital fark basınç ölçer ve U manometre ile ölçülen basınç kayıplarının karşılaştırılması.*

Table 1 and Figure 5 show that the pressure drop measurements carried out with the digital differential pressure meters and the U-tube manometer are quite similar. The highest pressure drop was measured as 0.65 kPa at the highest flow rate (≅1550 $Lmin^{-1}$). This measured pressure drop value in the main air line was quite below the value of 2 kPa, which is stated in various references as the highest value for main vacuum lines (ANSI/ASABE, 2016; Reinemann, 2019). It can be seen that the measured pressure drop values are close to the lower limit of the values of 0.85 to 1.7 kPa proposed by Spencer (1993) and that the results agree with each other.

Table 1 and Figure 5 show that the measurement results obtained with different methods are very close to each other. For this reason, the flow values measured in the digital air velocity meter during the measurement with the U-tube manometer (distilled water) were taken into account when determining the pressure drop with theoretical equations (6, 7 and 8) and CFD. The comparison results of the pressure drops calculated with theoretical equations and the measured values are shown in Figure 6.

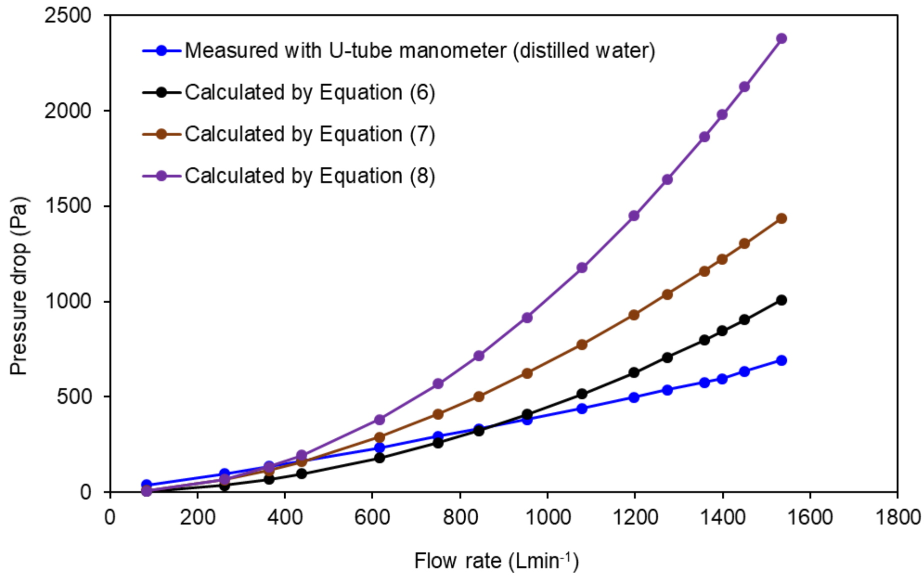

Figure 6. Comparison of the pressure drops measured with the U-tube manometer and calculated with the theoretical equations in the main air line of the pipeline milking system.

Şekil 6. *Süt sağım tesisinin ana vakum hattında U manometre fark basınç ölçer ile ölçülen ve teorik eşitliklerle hesaplanan basınç kayıplarının karşılaştırılması.*

Figure 6 shows that the measurement results and the pressure drops calculated using theoretical equation 6 are close to each other. It can be seen that there is a quite high difference between measured pressure drop values and calculated with equations (7 and 8) of the ANSI/ASABE and ISO standards. This difference increases with the value of the flow rate. Equations 7 and 8 are equations for calculating the pressure drops up to values around 3 kPa in main vacuum lines. As stated in the standards, these equations are often used to determine the safe minimum inner pipe diameter for specific flow rates and pipe lengths for main vacuum lines. Since these equations are used for satisfactory calculations, higher pressure drop values can also be calculated. The reason for this is that the friction factor is not taken into account in the equations. It can also be explained by the fact that values such as roughness, viscosity and density are calculated with a constant coefficient despite their changes.

The comparison results of the pressure drops determined by the CFD analysis using different turbulence models and the measured values are given in Figure 7.

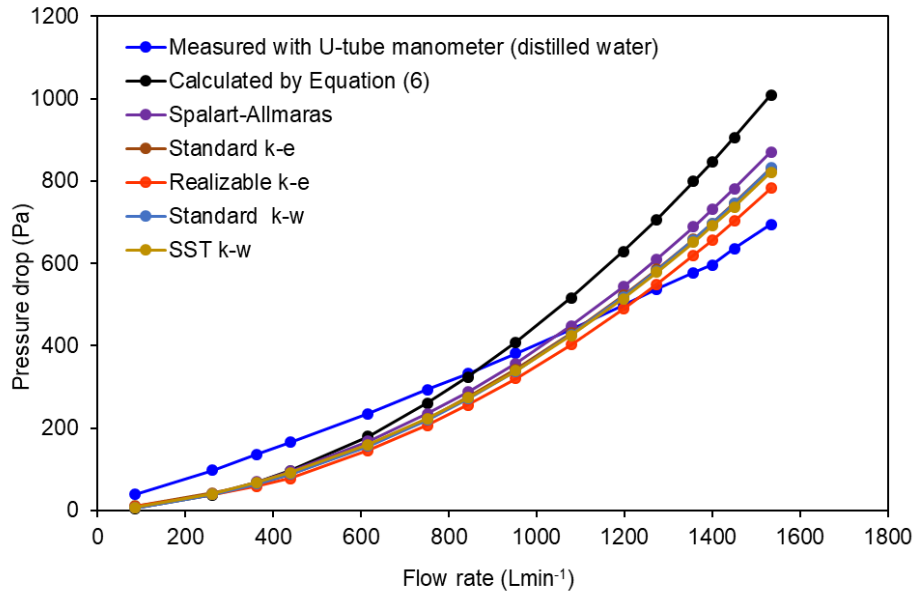

Figure 7. Comparison of the pressure drops measured, calculated and simulated with different turbulence models.

Şekil 7. *Ölçülen, teorik eşitlikler ve farklı CFD türbülans modelleri ile hesaplanan basınç kaybı değerlerinin karşılaştırılması.*

Figure 7 shows that the results calculated with different turbulence models are very close to each other. The pressure drops measured and calculated with theoretical equations and different turbulence models are also very close to each other. All turbulence models were statistically evaluated with measured values. The mean absolute error (MAE) and normalized root mean square deviation (NRMSD) criteria were used for the evaluation and the results are shown in Table 2.

Table 2. Statistical comparison of pressure drops measured and calculated with different turbulence models

Çizelge 2. *Ölçülen ve farklı türbülans modelleri ile hesaplanan basınç kayıplarının istatiksel karşılaştırması*

CFD turbulence models	MAE	NRMSD
Spalart-Allmaras	74.51	0.1335
Standart k-ε	66.03	0.1127
Realizable k-ε	58.99	0.0987
Standart k-ω	66.78	0.1135
SST k-ω	63.08	0.1067

The lowest MAE and NRMSD values for the pressure drops were found in the results calculated with the Realizable k-ε model. This result is well-matched with Mossad et al. (2009).

The results regarding the velocity and pressure changes of the air flow in the pipe determined with the Realizable k-ε turbulence model are shown in Figure 8.

Figure 8 shows that the velocity and pressure changes of the air flow in the pipe are most effective in the sweep bend and in the section after the sweep bend. The results regarding the velocity and pressure changes of the air flow at 0, 50, 100, 150, 200 and 250 mm after the sweep bend are shown in Figure 9.

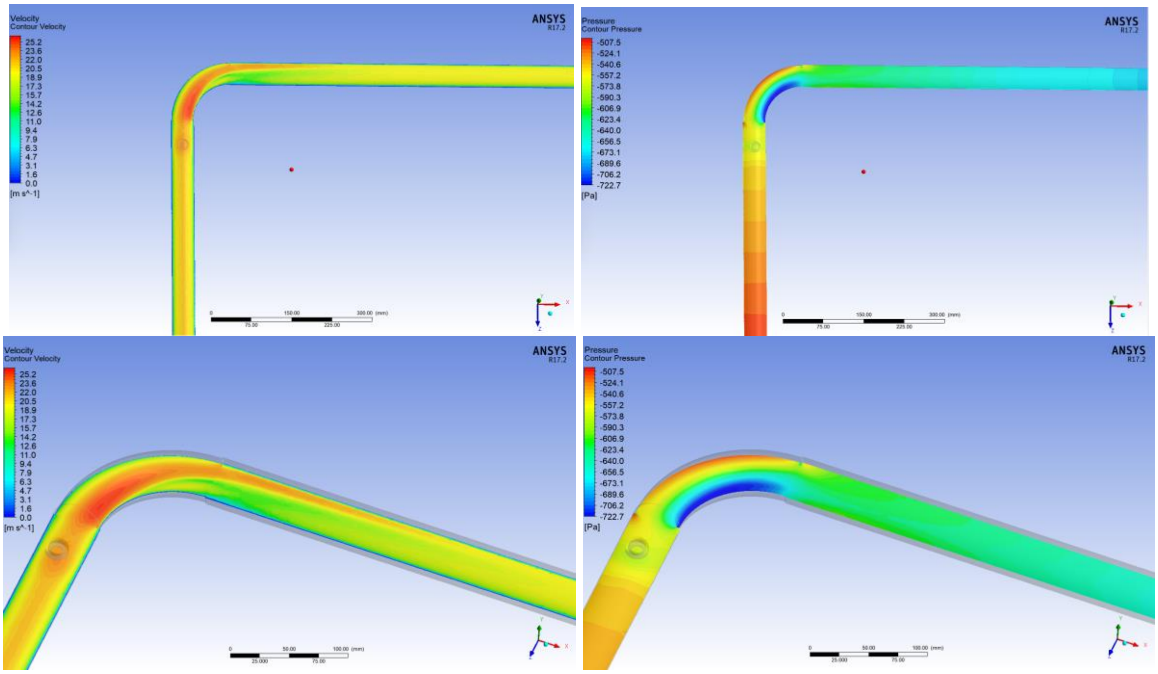

Figure 8. Flow velocity and pressure changes due to the air flow in a long sweep bend and a straight pipe section.

Şekil 8. *Düz boru ve dirsekte hava akımının oluşturduğu hız ve basınç değişimleri.*

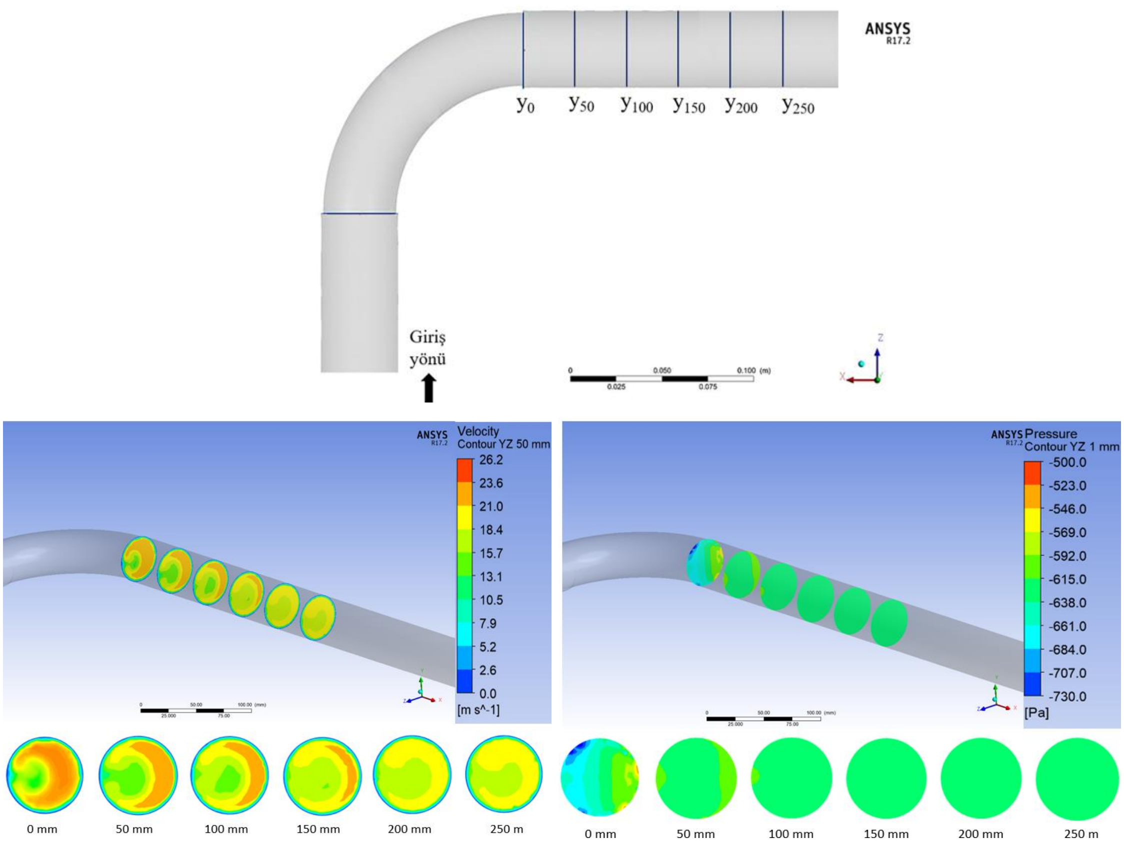

Figure 9. Velocity and pressure changes of the air flow in different straight pipe sections after the long sweep bend.

Şekil 9. *Hava akımının dirsekten sonraki farklı noktalarda oluşan hız ve basınç değişimleri.*

It was found that the change in flow velocity is quite effective in the inner and outer curvature sections of the sweep bend. In addition, in sections 0, 50, 100 and 150 mm downstream of the sweep bend, especially in the continuation of the outer curvature section of the sweep bend, it was observed that the velocity change in the flow is effective (Figure 9). After this section, the flow began to become uniform and the effect of the velocity change decreased.

It was observed that the pressure changes are particularly effective in the 50 mm section after the sweep bend. After this distance, the pressure distribution in the pipe becomes uniform. As mentioned in numerous references, it is important to consider a distance of at least 5D of the pipe inner diameter from the fittings to minimize the interaction of turbulence when measuring pressure and air velocity. Figure 9 shows that the connection of measuring devices in the inner and outer curvature sections of the sweep bend and near the inner and outer bends can cause measurement errors.

When the pressure changes at 0 mm downstream of the bend in Figure 9 are examined, it can be seen that even small changes in the diameters of the connections between the bend and the main pipe cause pressure changes. Therefore, the diameters of fittings and main pipe should be compatible to reduce pressure drops.

CONCLUSION

The measured pressure drops in the main air line of pipeline milking system were close to the pressure drops calculated with theoretical equations. However, the values calculated with the ANSI/ASABE equations are significantly higher than these values. This difference increases with the value of the flow rate. The calculation of the pressure drops using these equations given in the ANSI/ASABE standards can cause errors.

The results regarding the pressure drops determined with different turbulence models were statistically analyzed. The lowest MAE and NRMSD values for the pressure drops were found in the results calculated with the Realizable k-ε model. It can be said that the pressure drops in the main vacuum line can be estimated with minor error using the Realizable k-ε turbulence model and that it would be appropriate to use these values in the system design.

It has been observed that small changes in the diameters of the connections between the elbow and the main pipe cause pressure changes. Therefore, the diameters of fittings and pipe should be compatible to reduce pressure drops.

In CFD studies, it was found that the velocity and pressure changes of the air flow in the pipe are most effective in the sweep bend and in the section after the sweep bend. It was found that the velocity change of the flow is quite effective in the inner and outer curvature sections of the sweep bend. After 150 mm downstream of the sweep bend, the flow began to become uniform and it was observed that the effect of the velocity change decreased. It was observed that pressure changes were particularly effective in the 50 mm section downstream of the sweep bend. As mentioned in numerous references, it is important to consider a distance of at least 5D of the pipe inner diameter from the fittings to minimize the interaction of turbulence when measuring pressure and air velocity. Connecting measuring devices in the inner and outer curvature sections of the bend and near the inner and outer bends can cause measurement errors.

Data Availability

Data will be made available upon reasonable request.

Author Contributions

Conception and design of the study: DD, VD; sample collection: DD, VD; analysis and interpretation of data: DD, VD; statistical analysis: DD, VD; visualization: DD, VD; writing manuscript: DD, VD.

Conflict of Interest

There is no conflict of interest between the authors in this study.

Ethical Statement

We declare that there is no need for an ethics committee for this research.

Financial Support

This study did not receive funding from any organisation.

Article Description

This article was edited by Section Editor Dr. İkbal AYGÜN.

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