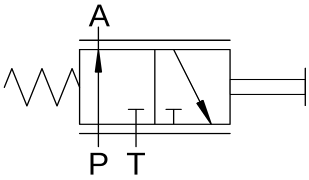
Sample Solution for Exercise: 1 Total Score: 15

Subtask	Sh	**Points**
1.1	+ high power density	0.5
	+ simple realization of linear movements	
	+ good controllability	0.5
	+ good time response behavior due to low mass inertia	
	+ simple and reliable overload protection	
	+ good lubrification and removal of heat losses by the fluid	
	- energy consumption (losses through friction and internal leakage)	0.5
	- maintenance of the fluid (susceptibility towards dirt and wear of the components)	
	- environment (noise emitted, leakage …)	0.5
1.2	environmentally friendly liquids	1
	viscosity group	1
1.3	$p = \frac{F}{A} \qquad Q = v \cdot A \Leftrightarrow A = \frac{Q}{v}$	1
	$p = v \cdot \frac{F}{Q} = 1\frac{m}{s} \cdot \frac{20\ kN}{30\ \frac{l}{min}} = 4 \cdot 10^7\ \frac{N}{m^2} = 400\ bar$	0.5
1.4	orifice	1
	$Q = \alpha_D \cdot A \cdot \sqrt{\frac{2}{\rho}} \cdot \sqrt{\Delta p}$	1

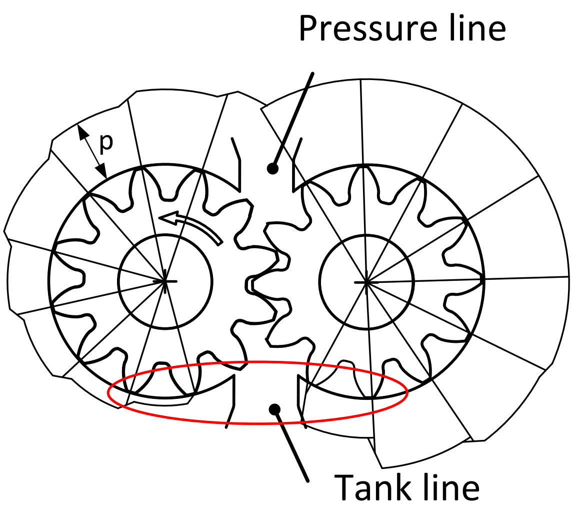
Subtask		**Points**
1.5	$p = \frac{F}{A_Z} \quad => \quad F = \Delta p \cdot A_Z$	0.5
	$A_Z = \frac{\pi}{4}(d_K^2 - d_Z^2) = 471.24\, mm^2$	0.5
	$p_P \cdot A_Z = p_{ND} \cdot A_Z + mg$	0.5
	$m = \frac{1}{g}(p_P - p_{ND}) \cdot A_Z = \frac{1}{9.81\, \frac{m}{s^2}} \cdot 205 \cdot 10^5 \frac{N}{m^2} \cdot 471.24\, mm^2$	0.5
	$= 984.75\, kg$	0.5
1.6	$c = \sqrt{\frac{E'_{Fl}}{\rho}} = \sqrt{\frac{16000 \cdot 10^5 \frac{N}{m^2}}{890 \frac{kg}{m^2}}} = 1340.8\, \frac{m}{s}$	1
	$t_{crit} = \frac{2 \cdot l}{c} = \frac{2 \cdot 6.7\, m}{1340.8\, \frac{m}{s}} = 9.994\, ms$	1
1.7	$\Delta p_{full\, surge} = \rho \cdot c \cdot \Delta v = 890\, \frac{kg}{m^3} \cdot 1340.8 \frac{m}{s} \cdot 8 \frac{m}{s} = 95.46\, bar$	1
	$\beta = \frac{t_{crit}}{t_{close}} = \frac{9.994\, ms}{18\, ms} = 0.555$	1
	$\Delta p = \Delta p_{full\, surge} \cdot \beta = 53.00\, bar$	1
	Alternative values: $\Delta p_{full\, surge} = \rho \cdot c \cdot \Delta v = 890\, \frac{kg}{m^3} \cdot 1500 \frac{m}{s} \cdot 8 \frac{m}{s} = 106.8\, bar$ $\beta = \frac{t_{crit}}{t_{close}} = \frac{12\, ms}{18\, ms} = 0.666$ $\Delta p = \Delta p_{full\, surge} \cdot \beta = 71.13\, bar$	
	Summation:	15

Sample Solution for Exercise: 2 Total Score: 10

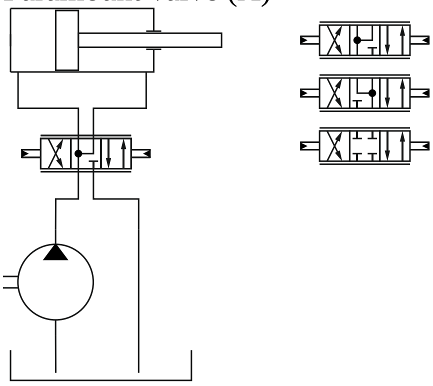
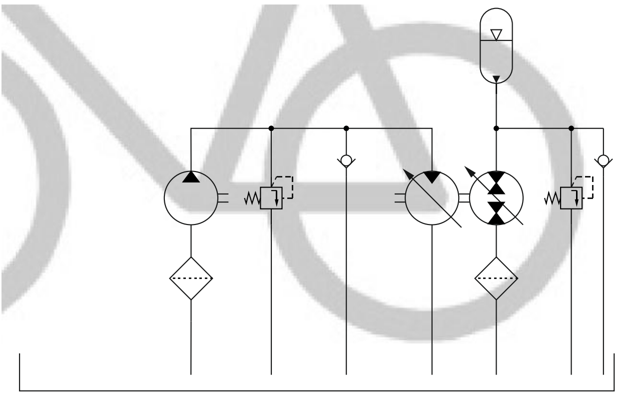
Subtask	Ro	Points
2.1		1.5
2.2	Pressure relief valves limit the inlet pressure by draining the fluid when the adjusted value is achieved. Pressure reducing valves keep the outlet pressure constant in spite of an unsteady inlet pressure or outlet flow rate. Under the condition that the inlet pressure is higher than the outlet pressure.	1.0
2.3	1. Impurity of the fluid can lead to deterioration, clamping etc => high pressure filter 2. Irregular pressure distribution at the spool perimeter e.g through asymmetrical flow can lead to radial forces which can cause clamping => peripheral grooves and/or symmetrically designed in- and outlets 3. Form errors can be the reason for radial clamping forces => increase production accuracy 4. Damage of the actuation e.g. through over-tension of electromagnets => safety feature in the control electronics 5. Damage of the valve seat i.e. due to high pressures, oscillations etc. => pressure relief valve and/or orifices in the control pipe	1.0
2.4	The accelerating force yields from Newton's law of motion $F_a = m\,\ddot{x}$ Coulomb's friction (solid body friction) from $F_{RC} = r \cdot \mathrm{sign}(\dot{x})$ and Newton's friction (liquid friction, dependent on viscosity and velocity) from $F_{RN} = \mathrm{d} \cdot \dot{x}$ Pre-tension spring force (proportional to the stroke) from $F_F = c \cdot x$ Flow forces from $F_{Str} = \mathrm{f}(Q, \dot{Q})$ and the pressure forces from $F_p = A \cdot \Delta p$	1.5

Subtask		**Points**
2.6	$$x_0 = \frac{\Delta p \cdot A_{\mathrm{RV}}}{c_{\mathrm{F}}} = 3.93\ \mathrm{mm}$$	0.5
2.5	$$Q = v_{\mathrm{A}} \cdot A_{\mathrm{A}} = 60\,\frac{l}{min}$$ $$\Delta p_{\mathrm{RV}} = \left(\frac{Q}{\alpha_D \cdot \pi \cdot d_{\mathrm{RV}} \cdot x_{\mathrm{RV}}}\right)^2 \frac{\rho}{2} = 3.13\ \mathrm{bar}$$ $$\frac{P_{\mathrm{RV}}}{P_{\mathrm{h}}} = \frac{\Delta p_{\mathrm{RV}} \cdot Q}{12\ \mathrm{kW}} = 2.61\ \%$$ ⇨ requirement is fulfilled	2.0
2.7	requirement: the opening forces (pressure force) need to be higher that the closing forces (spring force, flow force). $$\sum F = F_{\mathrm{p}} - F_{\mathrm{F}} - F_{\mathrm{Str}} \geq 0$$ The lowest positive total force occurs at maximum opening width of the check valve. Therefore only this point is taken into consideration. $$F_{\mathrm{p}} = \Delta p_{\mathrm{RV}} \cdot A_{\mathrm{RV}} = 24.59\ \mathrm{N}$$ $$F_{\mathrm{F}} = c_{\mathrm{F}} \cdot (x_0 + x) = 11.85\ \mathrm{N}$$ $$F_{\mathrm{Str}} = \rho \cdot \frac{Q_T^2}{\pi \cdot d \cdot x} \frac{\cos 60°}{\sin 60°} = 8.17\ \mathrm{N}$$ $$\sum F = 4.56\ \mathrm{N}$$ ⇨ valve opens completely and is pressed against the end stop	2.5
	Summation:	10

Sample Solution for Exercise: 3 Total Score: 10

Subtask	Sk	Points
3.1	Variable radial piston pump	0.5
3.2	1. piston, 2. cylinder star, 3. slipper, 4. stroke ring, 5. actuating piston	2.5
3.3	kinematically caused: through finite quantity of displacement rooms compression caused: through backflowing fluid in the displacement rooms during the reversing process in the high pressure area	1
3.4	$V = 2 \cdot e \cdot b \cdot (D \cdot \pi - a \cdot z)$ $d_{Rotor} = d_{Housing} - 2 \cdot l_{\min}$ $D_{Housing} = d_{Rotor} + 2 \cdot l_{\max} = 38 - 2 \cdot 1mm + 2 \cdot 7mm = 50\ mm$ $e = (l_{\max} - l_{\min}) / 2 = 3mm$ $V = 2 \cdot 2 \cdot 3mm \cdot 40mm \cdot (50 \cdot \pi - 4mm \cdot 6) = 63.88\ cm^3$	2
3.5	1. centrifugal force 2. pressure applied to bottom side of the vane	1
3.6	No, therfore a variable pump is necessary.	1
3.7		2
	Summation:	10

Sample Solution for Exercise: 4 Total Score: 10

Subtask	Di	Points
4.1	Orifices are independent of temperature and therefore are used preferencially. The design of the system can be done in one step for all temperatures.	1
4.2	Paramount valve (A) 	0.5
	Here both pressure chambers are connected with the high pressure, therefore only oil is required for the rod area for a fast process. Here the maximum velocity is the highest.	1
4.3		
	adjustable drive (pump or motor)	0.5
	system to accumulate braking energy (accumulator available) (only if the next two points are not reached)	0.5
	braking system is displacement controlled and works	0.5
	traction drive independent of accumulator load	0.5
	free-wheel possible	0.5
	pressure relief valves	0.5
	filter	0.5

Subtask	Di	**Points**
4.4	$p = 2\pi * M/V/\eta_{hm,motor}$	0.5
	$Q_{leak,\,motor} = k_p\, p + k_n\, n_{motor}$	
	$N_{pump} = (V_{motor}\, n_{motor} + Q_{leak,\,motor})/(\eta_{vol,\,pump}\, V_{pump})$	0.5
	n_{pump} = 4,846 U/min	0.5
4.5	$p = 2\pi\, M\, \eta_{hm,\,pump} / V$	0.5
	$M = M_{pedal}\, \eta_{hm,\,pump}\, \eta_{hm,\,motor}\, (V_{motor}/V_{pump})$ = 16,2 Nm	0.5
	$Q_{leak,\,motor} = k_p\, p + k_n\, n$	
	$Q = V_{motor}\, n_{motor} + Q_{leak,\,motor}$	0.5
	$\eta_{vol,\,motor} = (Q - Q_{leak,\,motor}) / Q$	
	$P = 2\pi\, n_{motor}\, M_{motor} / (\eta_{hm,\,motor}\, \eta_{hm,pump}\, \eta_{vol,\,motor}\, \eta_{vol,\,pump})$	
	P = 255,9 W	0.5
4.6	The volumetric efficiency factor increases and the mechanical one decreases.	0.5 0.5
	The oil is getting more viscous at lower temperatures so less leakage appears. Indeed the friction increases with higher viscosity.	
	Summation:	10

Sample Solution for Exercise: 5 Total Score: 15

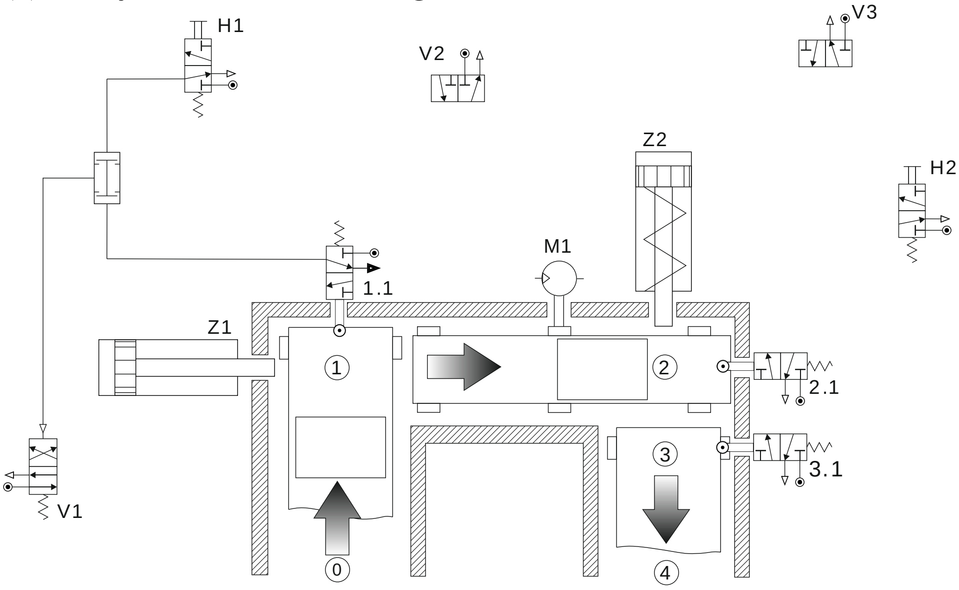
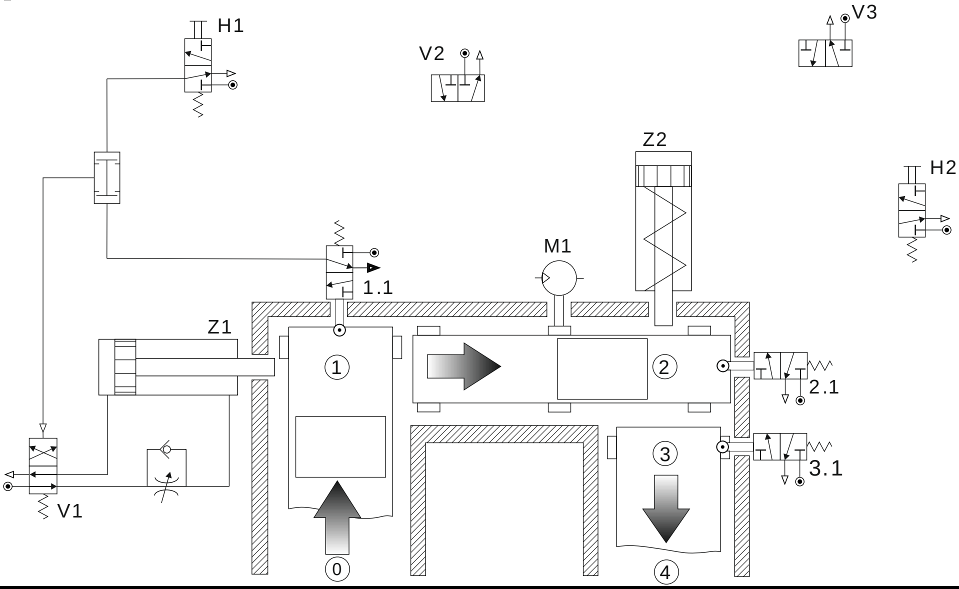
<table>
<tr><th>Subtask</th><th>vG</th><th>Points</th></tr>
<tr><td>5.1</td><td>lubricator,
pressure control valve,
filter of compressed air</td><td>1,5
0,5 per mentio-ning</td></tr>
<tr><td>5.2</td><td>a: slotted cylinder b: magnet cylinder
c: rope cylinder d: band cylinder</td><td>2
0,5 per mentio-ning</td></tr>
<tr><td>5.3</td><td>
<table>
<tr><th></th><th>benefit ☺</th><th>disadvantage ☹</th></tr>
<tr><td>mantenaince of the pressure medium</td><td>no ageing, no environmental pollution by leakage</td><td>filtration, mist lubrication, noise absorbtion or drying necessary</td></tr>
<tr><td>low viscosity</td><td>low system losses, high operating velocity</td><td>High losses through leakage, low damping</td></tr>
<tr><td>low operating pressure</td><td>pressure resistance of the construction elements umproblematic, use of tubing lines possible</td><td>lower forces and torques than in hydraulics</td></tr>
</table>
</td><td>3
0,5 per correct mentio-ning</td></tr>
<tr><td>5.4</td><td>calculation of the areas
$A_S = \pi \frac{d_S^2}{4} = 490{,}87\ mm^2$
$A_K = \pi \frac{d_K^2}{4} = 6361{,}73\ mm^2$
Balance of forces: $\sum F = 0$
$p_{Ver} \cdot A_K - p_{lower} \cdot (A_K - A_S) - p_U \cdot A_S - (m_L + m_S) \cdot g = 0$
$p_{lower} = \frac{p_{Ver} \cdot A_K - p_U \cdot A_S - (m_L + m_S) \cdot g}{A_K - A_S}$
$p_{lower} = \frac{6bar \cdot 6361{,}73mm^2 - 1bar \cdot 490{,}87mm^2m}{6361{,}73mm^2 - 490{,}87mm^2}$
$- \frac{(150kg\ + 20kg) \cdot 9{,}81 \frac{m}{s^2}}{6361{,}73mm^2 - 490{,}87mm^2} = 3{,}58bar$

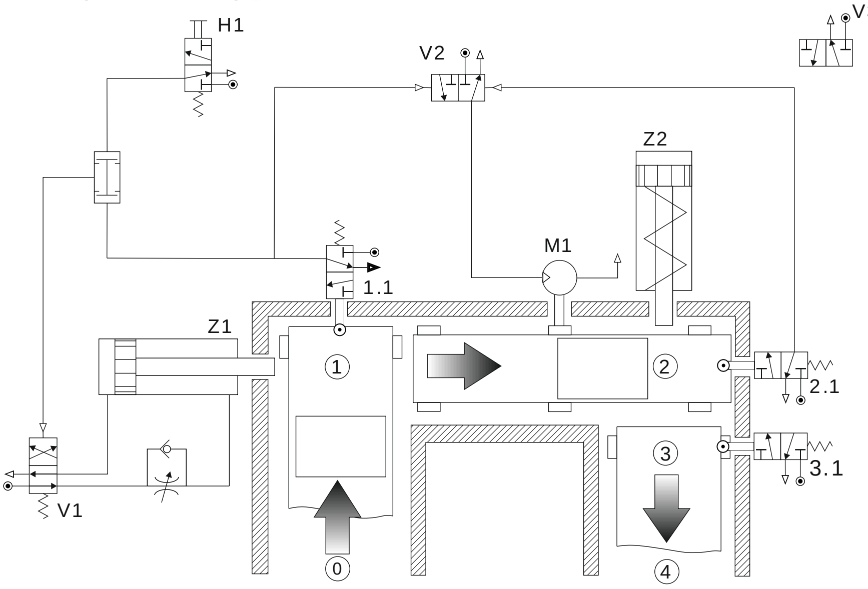
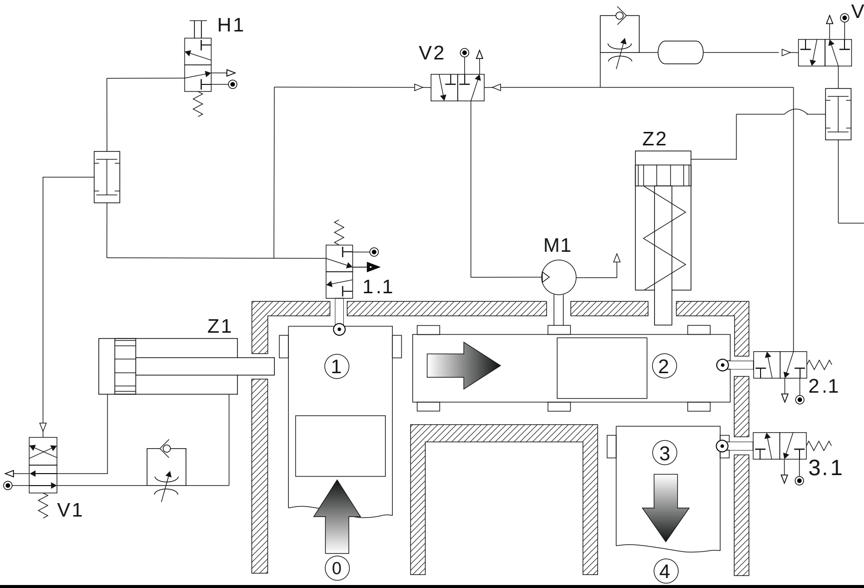
Check if critical flow of the exhaust air throttle is given:
$\frac{p_U}{p_{lower}} = 0{,}28 < b$ → critically floated and therefore independent of load as long as p_{lower} is not reduced by the load, so that a subcritical flow occurs.</td><td>2,5</td></tr>
</table>

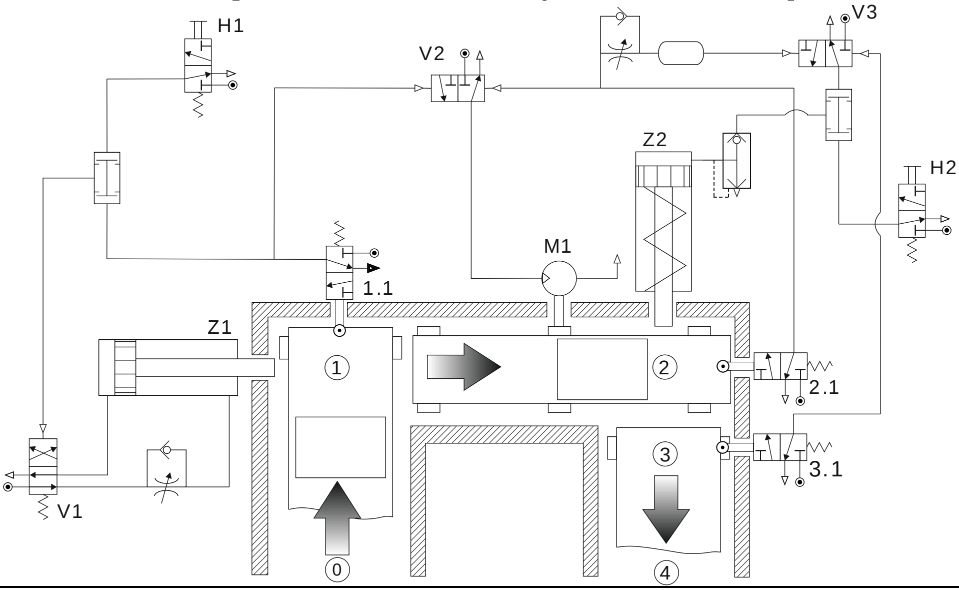
Subtask	vG	**Points**
5.5	Balance of forces: $\sum F = 0$ $p_{lower} \cdot A_K - p_U \cdot A_K - m_S \cdot g = 0$ $p_{lower} = \frac{p_U \cdot A_K + m_S \cdot g}{A_K} = 1{,}308$ bar Check if critical flow of the exhaust air throttle is given: $\frac{p_U}{p_{lower}} = 0{,}76 > b \rightarrow$ floated subcritically air mass in the cylinder from the ideal gas equation: $m_{cyl} = \frac{p_{lower} \cdot A_K \cdot h}{RT} = \frac{1{,}308bar \cdot 6361{,}73mm^2 \cdot 1000mm}{288 \frac{J}{kg\,K} \cdot 293{,}15K} = 9{,}86$ g acceleration and inertia are neglected $\rightarrow$ constant velocity and constant mass flow $\dot{m} = \frac{m_{cyl}}{t} = \frac{9{,}86g}{5s} = 1{,}972 \frac{g}{s}$ $\dot{m} = C_2 \cdot p_{lower} \cdot \rho_0 \cdot \underbrace{\sqrt{\frac{T_0}{T_{lower}}}}_{1} \sqrt{1 - \left(\frac{\frac{p_U}{p_{lower}} - b}{1 - b}\right)^2}$ $\Leftrightarrow \quad C_2 = \frac{\dot{m}}{p_{lower} \cdot \rho_0} \frac{1}{\sqrt{1 - \left(\frac{\frac{p_U}{p_{lower}} - b}{1-b}\right)^2}} =$ $\frac{1{,}972\frac{g}{s}}{1{,}308bar \cdot 1{,}1845kg/m^3} \frac{1}{\sqrt{1 - \left(\frac{\frac{1bar}{1{,}308bar} - 0{,}528}{1 - 0{,}528}\right)^2}}$ $\Leftrightarrow \quad C_2 = 1{,}47$ Nl/(bar s)	3
5.6	The move-out velocity stays unchanged because the exhaust air throttle provides the velocity and is still actuated by air.	1

Subtask	vG	**Points**
5.7	To gurantee a safe operation the bottle needs to be filled for 20 strokes with at least $p_{N2} \geq 6$ bar. mass over 20 strokes: $m_{cyl} = \frac{p_{Ver} \cdot A_K \cdot h}{R_{N2} T} \cdot 20 = \frac{6bar \cdot 6361{,}73mm^2 \cdot 1000mm}{296{,}8 \frac{J}{kg\,K} \cdot 293{,}15K} \cdot 20$ $= 877{,}41\text{g}$ basic filling oft he bottle at 6 bar: $m_{bo} = \frac{p_{bo} \cdot V_{bo}}{R_{N2} T} = \frac{6bar \cdot 20l}{296{,}8 \frac{J}{kg\,K} \cdot 293{,}15K} = 137{,}92\text{g}$ filling pressure of the bottle: $p_{bo,0} = \frac{(m_{cyl} + m_{bo}) \cdot R_{N2} T}{V_{bo}} = \frac{1015{,}33g \cdot 296{,}8 \frac{J}{kg\,K} \cdot 293{,}15K}{20l}$ $= 44{,}17\text{bar}$	2
	Summation:	15

Sample Solution for Exercise: 6 Total Score: 10

Subtask	St	**Points**
6.1	When the box arrives at workspace (1) **and** the operator confirms the end of the loading procedure with the hand switch H1, cylinder Z1 shall move out with the help of valve V1. As soon as the box has left working place (1), the cylinder shall move in again. 	2
6.2	To avoid damages of the goods the move-out of cylinder Z1 shall take place **cushioned**. 	1,5

Subtask		**Points**
6.3	**When** the box is at workspace (1), the second conveyor belt shall start and transport the box to working place (2). Make sure, that it is only conveyed as long as working place (2) is **free**. 	1,5
6.4	A delay that begins with the actuation of the push-down of button 2.1 shall be added to avoid an early actuation of hand switch H2. Just at the end of the delay and the actuation of the hand switch H2, cylinder Z2 can move out. Integrate valve V3 into the timing chain. 	3,5

Subtask		Points
6.5	As soon as the box reaches position (3) cylinder Z2 is moved in. To reduce the tact time, this process shall run off very **fast**. Plan an adequate method.  	1,5
	Summation:	10