Journal of Advances in Mechanical Engineering and Science, Vol. 3(2) 2017, pp. 1-13

RESEARCH ARTICLE

Design and Validation of an Oil Separating Accessory employed for Separating Oil Mix from Coolant

*Bandari Sanjanna[1], J Sreedhar[1], K Nageswara Rao[1], K.P Reddy[1]
[1]Assistant professor, Department of Mechanical Enginering, Sreyas Institute of Engineering and Technology, Beside Indu Aranya, GSI, Bandlaguda, Nagole, Hyderabad, Telangana 500068, India.

Received- 2 January 2017, Revised- 22 February 2017, Accepted- 29 March 2017, Published- 28 April 2017

ABSTRACT

There is an increasing demand to maintain the coolants that are used in machines. This is attributed to the fact that, if the coolants are not maintained properly, it would cause harm to both the machines and also to the workers. Therefore, this research work formulates to develop an accessory, usually an attachment which can isolate lubricating oil from coolant mix that is to be sent into a machine tool which requires a cooling fluid. The accessory manufactured in the research isolates the lubricating oil from the coolant with an extra-ordinary degree of purity so that; the coolant can be reused again into the machine. Once the coolant courses above the machine tool, it collects the oil that was utilized to grease the elements that move in the machine. Certain profits encompassed by the oil separation accessory manufactured to actively eliminate oil, which was found to be successful in meeting the benefits include, large amount of coolant recycling, easy maintenance, enhanced machining that escalates oil separation proficiency, upgraded tool life, prolonged coolant life, lessen coolant disposal, lessen operational and maintenance cost, uncontaminated working and healthy atmosphere for the workers. On the whole, a complete modern industrial design was envisaged.
Keywords: Coolant mix, Lubricating oil, Coolant recycling, Oil separation, Coolant disposal.

1. INTRODUCTION

The actions like cutting, metal forming, abrading etc., which are some of the lists of the metal functioning activities, have their particular cooling and lubricating specific requirements. The alteration in the appropriate mixing ratio causes steadiness of cooling and lubrication. In machines, the lubricating oil used for lubrication, paves its path into the coolant and is ultimately directed into the coolant tank, which is also called as sump. It is a must for every action that happen in the machines to be estimated individually to check the exact level of concentration of the oil that is mixed in the coolant. Coolants are used extensively to drive away the heat that is produced by friction while the machine is in process, and is also used as an agent for lubrication. It also provides better surface finish, longer tool life, narrower tolerances of the work piece size, lower energy consumption and cleaner cutting zone. The emulsion coolant or the coolant which is soluble by water is the most widely utilized agent for cooling and lubrication in machine tools. Coolants never wear out. Subsequent usage makes the coolant prone to contamination by tramp oil, burrs, chips, external hydrocarbons, oxides, particulates of the processed metals, oxidation products, micro-organisms, alienated emulsion oil and also produces foul smell because of the contamination of bacteria, leading to a situation, where the coolant can never be utilized any more, leading to its disposal. Disposing the coolants effectively requires more money and it can deleteriously affect the environment too. Therefore, the profit and loss regarding the machines that makes use of coolants usually depends on the entire cost for the coolant and managing the coolant effectively. The process of prior isolation of the lubricating oil from the coolant mix saves money due to machine’s increased effectiveness as well as the enhanced product

*Corresponding author. Tel.: +919542211440
Email address: bandarisanjay1@gmail.com (B.Sanjanna)
Double blind peer review under responsibility of DJ Publications
https://dx.doi.org/10.18831/james.in/2017021001

quality. So, there is a need for a novel accessory or attachment for isolating lubricating oil from coolant mix.

Coolant is a liquid used in metal functioning activities, in order to reduce the friction that occurs between the tool and the piece involved in the work [1]. Coolants are also termed as Metal Working Fluid (MWF) or cutting fluid. Coolants are framed to function with specific metals involving specific conditions. A best coolant involves high thermal capacity, low viscosity, non-toxicity, chemical inertness and non-corrosive [2]. Some applications also need the necessity that the coolant should exhibit an electrical insulator property [3]. The coolant can have its own liquid or gaseous phase, or it can undertake a change in phase, with latent heat being added to the cooling efficiency of the coolant. The process of evaporation modifies concentration of the coolant. Oil which is a bad medium of heat transfer lessens the feeds and quickens the machine tools. This is pretty expensive. On the other hand, water acting as pre-eminent coolant is always available, in-expensive, and provides a good heat transfer capacity; however it does not have properties of lubrication and its tendency to rust makes it inappropriate to be used. All these issues together suggest emulsion’s usage. Emulsion is a lubricant which is dispersed in a phase of water for all the exact requirements [4-7]. To make sure that the lubrication reduces friction between the metal parts that are in contact, an emulsion is formed by mixing oil and water together. Usually oil and water never mix together. To hold water and oil particles together, an emulsifying agent is added. The agents of emulsification are generally inorganic while oil is of organic in nature. The following issues must be engaged for an appropriate choice of the coolant [8]. They are, metal working operation process, metal to be machined, corrosion sensitivity of the metal and hardness of the water. Coolant analysis depends on the factors like, brix, pH, concentration, tramp oil, dirt, bacteria, fungus, conductivity and hardness of water [9].

Lubricant oil is an ingredient presented to diminish abrasion between surfaces that are moving. It may possibly involve the function of moving alien elements and heat distribution. Lubricity is referred to as the property that reduces friction. A typical lubricant contains 90% of base oil (it is the often used petroleum fractions, termed as the mineral oils) and less than 10% of additives. Vegetable oils or synthetic liquids like hydrogenated polyolefins, esters, silicones, fluorocarbons and several others are at times utilized as base oils. Additives provide minimized friction and wear, augmented viscosity, enhanced viscosity index, resistance towards corrosion and oxidation, aging or contamination, etc. [10]. The functions of lubricant oil are, controlling friction and wear, controlling temperature and corrosion, electrical insulation and hydraulic power transmission, contamination removal (flushing action) and seal formation (grease). The types of lubricant oil are, solid lubricant oils, liquid mineral lubricant oils, synthetic liquid lubricant oils and greases.

The lubricants, which include both organic and inorganic substances minimize the friction, lessen the surface of friction wear and prevent damage of the machine in order to enhance the efficiency of the machine [11]. Crude petroleum that forms the basis of lubricants varies in molecular weight from 150 to over 1000 and can be created by numerous refining processes [12, 13]. A gas, liquid, or solid lubricant prevents connection of parts in relative motion, and so lessen the abrasion and wear. In several machines, cooling involving the lubricants is very essential [14-17]. Non-liquid lubricants include grease, powders (dry graphite, molybdenum disulphide, tungsten disulphide, etc.), teflon tape used in plumbing, air cushion and others [18, 19].

Once a new coolant is in, concentration control is the most important parameter for a coolant to be monitored. As a rule of thumb, steadiness in concentration can be accomplished only by adding dilution which is weak to half of the goal concentration at all times. If the goal concentration is 7% every time add 3.5% concentration. To regulate the concentration of coolant, a device called automatic coolant proportioner is attached to the machines.

Coolants are calculated to operate at the least concentration of 4% in the ratio of 1:25 (oil: water). A lower concentration than the above, even for a small period, can cause machines and work piece to corrode. Lower concentration of coolant, will cause growth of bacteria as well as other problems [20-22]. The bacterial growth in turn affects the machine. For frequent examination of concentration on daily basis, hand held refractometer is used.

This is faster than the steps followed in the laboratory.

Common problems of the Computer Numerical Control (CNC) coolants are, corroded parts, insufficient lubrication, lesser sump life, extreme lathering, discoloration and extreme bacterial growth, difficulties holding part tolerances or dimensions, tapping, surface finish, and reduced tool life, fog, mist, or smoke filled atmosphere, health complications: dry hands and arms, dermatitis, breathing problems for the employees etc., [23, 24]. Some coolants take away paint, seals, and other components of the machine tool. The free oil contamination paves way for growth of bacteria. So, it must be kept clean. Better emulsion has resulted in increasing cost [25]. The load of the machine must also be balanced [26]. The contaminants in coolant may be due to contamination of tramp, lubricant oil, solids or due to water quality [27]. The demand in the escalating need regarding the performance of the cooling systems, has led to technologies that use Nano fluid coolants, which was investigated and studied [28, 29]. As it is a need to have lubricants to sooth the motion of the tools available in the machines, a better liquid lubricant was discussed with recent developments in friction modifiers [30].

Some of the equipment required to separate oil from coolants are, skimmers, coalescers, centrifuges, flotation and oil absorbent pillows. The heat that is transported was cooled properly by equipment involved in coolants [31].

The oil separators are also commonly known as oil-water separators or oil and water separators or oil-coolant separators. The technology that involves a mesh for oil/water separation to clean-up the oil wastes in the form of the oily waste water that uses a superhydrophillic and underwater superoleophobic mesh was studied in [32]. The technology of involving mesh membranes with capillarities to separate oil and water from waste water was studied, as it is very important to prevent ecological damage [33]. A one step spraying method that involves in the separation of oils from water was studied [34]. Investigation on properties of cooling and lubrication of supercritical carbon dioxide sprays which functions to cool and lubricate the machines was studied in [35].

1.1. Oil separation techniques

Oil separation techniques involving the process of isolating oil from the coolant mix are divided into settlement, magnetic attraction and passage through filter media. Settlement technique paves way for the production of several varieties of equipment for separation of oil such as, dredged tanks, hydrocyclones, centrifuges, hinged belt, and drag conveyors. [36] Magnetic attraction leads to the production of several varieties of equipment for separation of oil such as, magnadrums, magnetic conveyors, tramp iron traps, and sump plugs. Passage through filter media technique leads to manufacture of many types of equipment for separation of oil such as, universal clarifiers, hydrostatics, vacuum filters, rotary drums, pre-coat filters, and cartridge filters.

This present paper involves introducing an attachment to separate oil mix to meet the purpose stated above. The project work has various phases that involves, a new concept and method for oil separation process using sponge, development of the conceptual design of oil separating accessory, solenoid valves to control pneumatic cylinders actuation, speed control valves to control air supply to the pneumatic cylinders, analysing the cost estimation of oil separating accessory, trials for checking oil separating accessory work for the oil separation process, validation trials for different cases with their respective time intervals, calculations for different aspects of oil separation process, calculations to find efficiency of accessory with different time intervals, comparison of belt type oil separator with the current work, verification of accessory to overcome belt type oil separator limitations and calculations for efficiency check between belt type separator and accessory. The research work proposed, thus frames a whole industrial design to eliminate oil from the coolant.

2. DESIGN METHODOLOGY

2.1. Design of components used

- Coolant tank: Figure 1 displays a photograph of coolant tank which is used for coolant storage and circulation. The tank is of a standard rectangle shape which is made up of steel material type. All the dimensions that are involved in the construction of the components are in mm and in first angle projection.

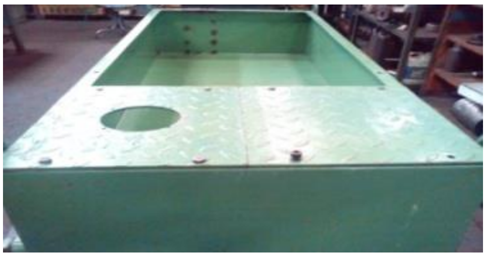

Figure 1.Photograph of coolant tank

- Pneumatic cylinder: The pneumatic cylinders or air cylinders change air pressure into linear motion and also makes use of the power of the compressed gas to create energy in a linear motion. The body of cylinder is made up of aluminium material type and the cylinder used in this work has bore size of 12 mm with 150 mm of stroke length.
- Supporting blocks: They are used to firmly hold the guide rods on coolant tank edges. These are rectangular blocks which are made up of cast iron material type. Figure 2 shows 2-dimensional drawing of the supporting block.

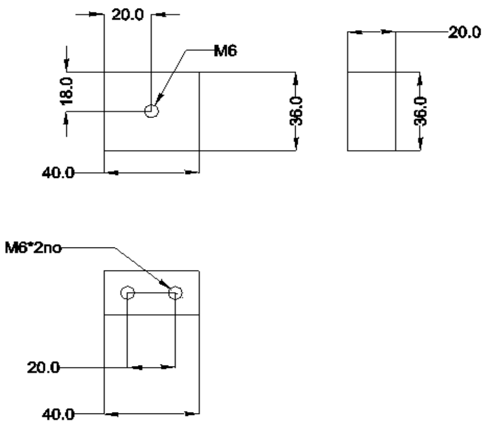

Figure 2.Supporting block drawing

- Fasteners: They are made up of steel material type. Standard M5, M6, and M10 hallen bolt and nut are used for fixing many components.
- Springs: It is used to control impact forces created at linear motions. Standard coiled type springs which are made up of steel material type of 2mm and 5mm with 10mm diameter is used.
- Guide rods: It is held by supporting blocks on tank edges to support moving blocks for linear movements. Round steel material type of rods is used.
- Moving blocks: They are attached to the oil tray and mounted on the guide rods. These are of rectangular blocks which are made up of cast iron material type. Figure 3 shows 2-dimensional drawing of moving block.

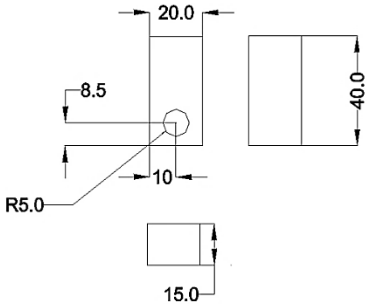

Figure 3.Moving block drawing

- Oil tray: It is placed on guide rods to collect oil after pressing process by sponge setup. Rectangular shaped tray is used which is made up of sheet metal material type and figure 4 shows 2-dimensional drawing of oil tray.

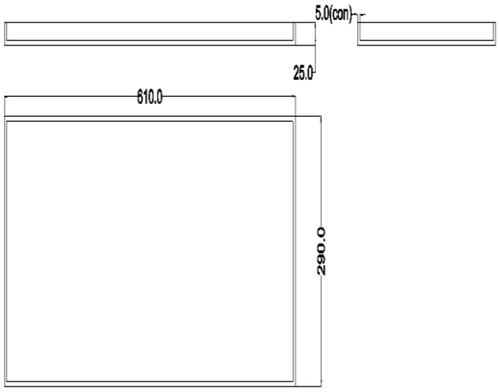

Figure 4.Oil tray drawing

- Angle bracket: It is fixed to the piston rod to hold sponge holder. A right angle shaped bracket made up of steel material type is used.
- Supporting rods: They are attached to the angle bracket to carry the load along with the piston rod. Round steel material type rods are used.
- Clamp plate: Rectangular shaped plate is used which is made up of sheet metal material type and figure 5 shows 2-dimensional drawing of clamp plate. All dimensions are in mm and in first angle projection.
- Sponge holder: Rectangular shaped block made up of sheet metal material type is used.

- Sponge pressing block: A rectangular shaped block made up of sheet metal material type is used. Figure 6 shows 2-dimensional drawing of sponge pressing block

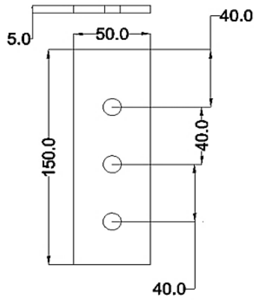

Figure 5.Clamp plate drawing

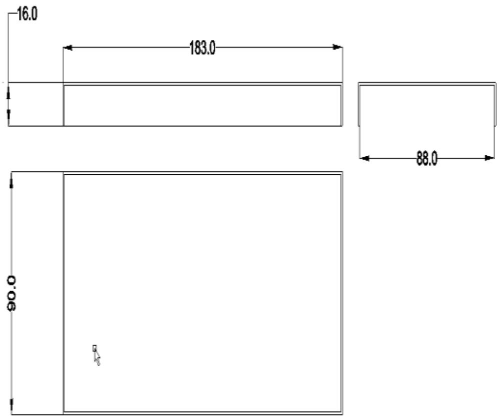

Figure 6.Sponge pressing block drawing

Solenoid valve (single phase, 110V and 50 hertz type valve), air fitting (plastic type push back air fittings), speed control valve (screw controlled, plastic type valve), Tee union (two branches, plastic type connector), metal fitting (thread cutted, steel material type), transformer (220 to 110 voltage type), electrical switch (plus type switch), tools used (screw driver, hallen key, cutter, cutting plier, spanner, etc.) are used for this project.

Figure 7 shows the photograph of development of an oil separating accessory. The accessory is designed to separate floating lubricant oil in the coolant tank.

2.2. Accessory design

2.2.1. Stress evaluation on guide rods

Number of guide rods used=2, Dimension: Length= 800mm and Diameter=10mm, Material used: Steel 310 (¾ hard), Yield stress=1120Mpa, Young's modulus=210Gpa, Area=3.14×diameter× length=3.14×10×800=25120mm^2, Stress on rods=load/area of rods=0.5/0.25120=19.9pa (N/mm^2). The weight of oil tray placed on the guide rods can be neglected because it is made up of sheet metal material type. The stress produced on the guide rods is much lesser than the yield stress. So, the design is well within the limits and hence the design is safe.

Figure 7.Photograph of oil separating accessory

2.2.2. Stress evaluation on angle bracket

Dimension: length×breadth×height= 290mm×50mm×3mm×105mm×50mm×3mm.
Material used: Steel 310, Yield stress=1120Mpa, Young's modulus=210Gpa, Area=length×breadth=290×50=14500mm^2.
Stress on clamp=load/area=0.5/14500=34.48 pa. The weights of the sponge and sponge holder are rejected here.
Here N=Newton, pa=pascals, Mpa=Mega pascals, Gpa=Giga pascals. Load generated by the movement of the piston=load=0.5 N.

Table A1 shows the details of bill of material and cost estimation of the complete components that were used in the current work. It shows a brief description of material type used and the selected design of each component.

3. WORKING AND VALIDATION TRIALS

3.1. Working of oil separating accessory

The working of oil separating accessory involves the following seven steps.
Step 1: Falling time - The initial position of the oil separating accessory is the sponge setup that is held vertically by piston rod. In this, sponge is immersed in the coolant mix and the time taken for this action is called as falling time, noted as "Fa".
Step 2: Dipping time-Here, the sponge is immersed into the coolant mix and the time interval given for sponge to absorb the

lubricant oil which is floating on coolant in the tank. The time interval given for this process is called as dipping time and the time is noted as "Di".

Step 3: Dwelling time-After the dipping action, the sponge setup is made replaced to its initial position by piston movement and the time taken for this action is called as rising time, time is noted as "Ri". The time interval given for this process is called as dwelling time and the time is noted as "Dw".

Step 4: Oil tray movement-In this, the oil tray setup is moved horizontally towards sponge setup by piston stroke length. The oil tray is moved by using their moving blocks which are mounted on guide rods. This is shown in figure 8. The tray is placed perpendicularly to the sponge and the time taken for this action is noted as "TMf".

Figure 8.Photograph of oil tray movement process

Step 5: Pressing time-When the oil tray setup is placed perpendicularly under the sponge material, the sponge setup is made to press on the pressing block which is attached in the oil tray. The processing time is known as pressing time and the time is noted as "Pr".

Step 6: Rising time-After the pressing action, the sponge setup is made to release from pressing block and replaced to its initial position. This time is said to be rising time and the time is noted as "Ri". Figure 9 shows the photograph of the rising time of the process.

Figure 9.Photograph of rising time process

Step 7: Oil separated–By the pressing action, the lubricant oil sticking to the sponge material is released and collected in the oil tray. After the rising time process, the oil tray is moved back to its initial position by piston stroke. Here the oil tray is moved in backward direction and the time taken is noted as "TMb". By applying suitable time intervals, effective oil separation can be achieved. So by varying these above time intervals, validation trials are carried out to check the efficiency of oil separating accessory. Figure 10 shows the photograph of the oil separation process.

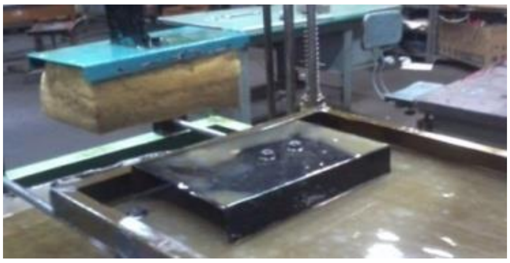

Figure 10.Photograph of oil separated process

3.2. Validation trials of oil separating accessory

Here the units are, S=time in seconds and ml=amount in millilitres. The calculation to find the amount of oil mixed in the tank per day is the same for all cases from 1 to 4 and it is calculated as, the regular amount of oil mixing in CNC machines as 100ml per hour. For 1 shift it is 8 hours and the amount of oil mixed per shift is the amount of oil mixed per hour multiplied by 8 which is 800ml/shift and for 3 shifts it is 2400ml. So the amount of oil mixed in the tank per day is 2.4 litres. The formula to find the average amount of oil separated per hour is given by equation (3.1)

$$\text{Average amount of oil separated per hour} = \text{average cycles per hour} \times \text{average amount of oil separated per cycle} \quad (3.1)$$

The formula to find the required cycles for separation of oil mixed per day is given by equation (3.2)

$$\text{The required cycles for separation of oil mixed per day} = \text{average time} \times 60 \,/\, \text{average time per cycle} \quad (3.2)$$

Case 1: Table A2 shows the validation trials carried out by varying dipping time, and keeping dwelling time and pressing time constant. In this case, the average time for 1 cycle is 51.3 seconds. Therefore, an average cycle per hour is 70.1 cycles per hour which is approximately 70 cycles per hour. The average amount of oil separated per cycle is 30.8ml. From equation (3.1), the average amount of oil separated per hour is 2156ml which is 2.15 litres per hour. Therefore, an average time of 66.6 minutes is needed for oil separation mixed per day. By equation (3.2), the required cycles for separation of oil mixed per day are approximately 78 cycles.

Case 2: Table A3 shows validation trials carried out by varying dwelling time, and keeping dipping time and pressing time constant. In this case, the average time for 1 cycle is 50.6 seconds. Therefore, an average cycle per hour is 71.1(~71) cycles. From the above table, the average amount of oil separated per cycle is 32ml. From equation (3.1), the average amount of oil separated per hour is calculated to be 2272ml, which is 2.27 litres per hour. Therefore, the required time in average for the separation of oil mixed per day from accessory is calculated as 63.4 minutes. From equation (3.2), the required cycles for separation of oil mixed per day from accessory are calculated as 75.1 (~75) cycles.

Case 3: Table A4 shows validation trials carried out by varying pressing time, and keeping dipping time and dwelling time constant. In this case, the average time for 1 cycle is 51.2 seconds. Therefore, an average cycle per hour is 70.3 (~70) cycles per hour. From the table, the average amount of oil separated per cycle is 30.2ml. From equation (3.1), the average amount of oil separated per hour is 2114ml which is 2.11 litres per hour. Therefore, an average time of 68.2 minutes is needed for oil separation of oil mixed per day. From equation (3.2), the required cycles for separation of oil mixed per day from accessory is calculated to be 79.9 cycles which is approximately 80 cycles.

Case 4: Table A5 shows validation trials carried out by varying all dipping time, dwelling time, and pressing time. In this case, the average time for 1 cycle is 49.7 seconds. Therefore, an average cycle per hour is 72.4, which is approximately 72 cycles per hour. From the above table, the average amount of oil separated per cycle is 28.6ml. From equation (3.1), the average amount of oil separated per hour is calculated as 2059.2ml. which is 2.05 litres per hour. Therefore, an average time of 70.2 minutes is needed for oil separation of oil mixed per day. From equation (3.2), the required cycles for separation of oil mixed per day from accessory is 84.7 cycles which is approximately 85 cycles.

3.3. Comparison of all cases

Figure 11 shows the graph for the comparison of all above cases with their respective time intervals. By these above trials and calculations, it is clear that by varying dwelling time, high efficiency of oil separation can be achieved with less working time interval. This is schematically shown in figure 11 as a plotted graph.

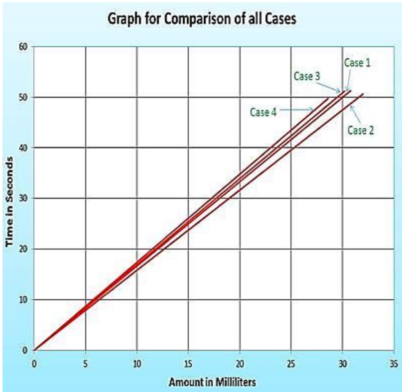

Figure 11.Graph for comparison of all cases

3.4. Belt type oil separator

The belt type oil separator features a revolutionary new oleophilic belt and a unique method of stripping the separated oil from the belt. The typical belt type oil separator is shown in figure 12 for further references.

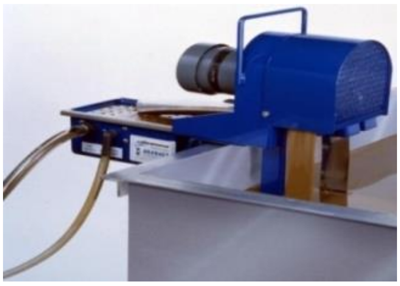

Figure 12.Belt type oil separator

3.5. Efficiency of separators

Regular amount of oil mixing in CNC machines per day is 2.4 litres. The amount of oil separated per hour by belt type oil separator and oil separating accessory techniques are briefed below. For the separator techniques given below, the formula to find the efficiency of separators is given in equation (3.3) as,

$$\text{Efficiency of separator} = (\text{oil separated}/\text{hour}/\text{oil mixed}/\text{day}) \times 100 \quad (3.3)$$

3.5.1. Belt type oil separator

The oil separated is 2 litres per hour. But the efficiency which is calculated by using the equation (3.3) is 83.33%. Therefore, oil mixed per day in CNC machine is separated at 83.33% efficiency in an hour.

3.5.2. Oil separating accessory

The oil separated is 2.27 litres per hour. By using equation (3.3), the efficiency is 94.58%. Therefore, oil mixed per day in CNC machine is separated at 94.58% efficiency in an hour.

Figure 13 shows the graph for the efficiency comparison between oil separating accessory and oil belt separator. So by the above calculations, it is clear that the efficiency of oil separating accessory is higher than belt type oil separator.

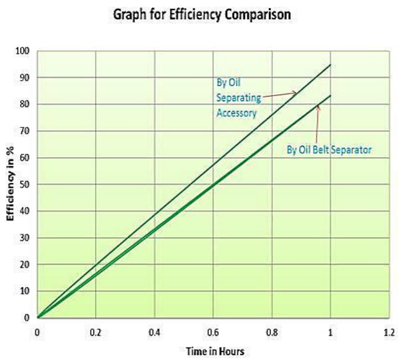

Figure 13.Graph for efficiency comparison

3.6. Comparison between oil separating accessory and belt type oil separator

Table A6 shows comparison between oil separating accessory and belt type oil separator. By these comparisons of oil separating accessory with the present vastly used belt type separator, the result shows that the oil separating accessory has overcome many limitations of belt type separator. So this proves that the design and development of oil separating accessory of this work is safe and effective for practical applications.

4. CONCLUSION AND FUTURE ENHANCEMENT

4.1. Conclusion

The project work is headed towards a lubricating oil-coolant isolating accessory that separates oil from the coolant to achieve higher coolant purity so that it can be recycled back into the machine tool. It reduces the machine's operational cost by decreasing the amount of coolant supply. Oil separation and recycling process done in this work can significantly extend the coolant's life, enhance recycling of enormous amount of coolant, increase the productivity, increase tool's life, decrease the operating costs, diminish coolant disposals, lessen the health risks to workers and increase the manufacturing quality. Thus the main intend of the project in structuring a whole industrial framework to eliminate oil from the coolant was framed successfully to meet the goals.

4.2. Future enhancement

Oil separating accessory can be done automatically by controlling the pneumatic cylinders using PLC (Programmable Logic Controller). PLC has developed a new universal control device. PLC is completely integrated to computer systems to control action. Then according to the type of work required, the programs are entered and the work will be completed automatically within a single step. Thus by including PLC in this work, the accessory's working can be made more trustworthy and flexible.

REFERENCES

[1] Saeed E.Awan, Nasir M.Mirza and Sikander M.Mirza, Kinetic Study of Fission Product Activity Released Inside Containment under Loss of Coolant Transients in a Typical MTR System, Applied Radiation and Isotopes, Vol. 70, No. 12, 2012, pp. 2711-2719, http://dx.doi.org/10.1016/j.apradiso.2012.08.002.

[2] A.S.Kumar, M.Rahman and S.L.Ng, Effect of High-Pressure Coolant on Machining Performance, The International Journal of Advanced Manufacturing Technology, Vol. 20, No. 2, 2002, pp. 83-91, http://dx.doi.org/10.1007/s001700200128.

[3] J.H.Park, T.Domenico, G.Dragel and R.Clark, Development of Electrical Insulator Coatings for Fusion Power Applications, Fusion Engineering and Design, Vol. 27, 1995, pp. 682-695,

https://doi.org/10.1016/0920-3796(95)90184-1.

[4] E.Brinksmeier, C.Heinzel and M.Wittmann, Friction, Cooling and Lubrication in Grinding, CIRP Annals-Manufacturing Technology, Vol. 48, No. 2, 1999, pp. 581-598, https://doi.org/10.1016/S0007-8506(07)63236-3.

[5] R.Sivasubramaniyam and K.Maniysundar, Performance Analysis and Heat Transfer Studies on Protruding Surfaces of Electronic Components, Concurrent Advances in Mechanical Engineering, Vol. 1, No. 1, 2015, pp. 37-60, http://dx.doi.org/10.18831/came/2015011005.

[6] N.Diaz, E.Redelsheimer and D.Dornfeld, Energy Consumption Characterization and Reduction Strategies for Milling Machine Tool Use, Glocalized Solutions for Sustainability in Manufacturing, 2011, pp. 263-267, http://dx.doi.org/10.1007/978-3-642-19692-8_46.

[7] S.R.Majumdar, Pneumatic Systems: Principles and Maintenance, Tata McGraw-Hill Education, New Delhi, 1996, pp. 112-133.

[8] J.Webster, Selection of Coolant Type and Application Technique in Grinding, Supergrind 11, 1995, pp. 205-218.

[9] R.R.Srikant and D.N.Rao, Applicability of Cutting Fluids with Nanoparticle Inclusion as Coolants in Machining, Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, Vol. 223, No. 2, 2009, pp. 221-225.

[10] L.K.Hudson, J.Eastoe and P.J.Dowding, Nanotechnology in Action: Overbased Nanodetergents as Lubricant Oil Additives, Advances in Colloid and Interface Science, Vol. 123, 2006, pp. 425-431, http://dx.doi.org/10.1016/j.cis.2006.05.003.

[11] R.M.Mortier, S.T.Orszulik and M.F.Fox, Chemistry and Technology of Lubricants, Vol. 107115, Springer, London, 2010, pp. 77-105.

[12] D.Klamann and R.R.Rost, Lubricants and Related Products: Synthesis, Properties, Applications, International Standards.Verlag Chemie, 1984.

[13] T.Mang and W.Dresel, Lubricants and Lubrication, John Wiley & Sons, Germany, 2007, pp. 44-59.

[14] D.M.Pirro and A.A.Wessol, Refining Processes and Lubricant Nase Stocks, Lubrication Fundamentals, 2001, pp. 257-292.

[15] George E.Totten, Handbook of Lubrication and Tribology: Volume I Application and Maintenance, Vol. 1, CRC Press, New York, 2006, pp. 19.1-19.19.

[16] L.R.Rudnick and R.L.Shubkin, Synthetic Lubricants and High-Performance Functional Fluids, Revised and Expanded, CRC Press, New York, 1999, pp. 239-252.

[17] H.P.Bloch, Practical Lubrication for Industrial Facilities, The Fairmont Press, USA, 2009, pp. 1-42.

[18] W.L.Robertson, Lubrication in Practice, Vol. 27, CRC Press, United Kingdom, 1984, pp. 1-14.

[19] R.Pugazhenthi, R.Saravanan and M.Anthony Xavior, A New Heuristic for Modern Manufacturing Environment Scheduling Problems, Journal of Advances in Mechanical Engineering and Science, Vol. 1, No. 1, 2015, pp. 1-11, http://dx.doi.org/10.18831/james.in/2015011001.

[20] Occupational Safety and Health Administration, Metalworking Fluids: Safety and Health Best Practices Manual, Salt Lake City: U.S. Department of Labor, Occupational Safety and Health Administration-1999.

[21] Nathan Rosenberg, Technological Change in the Machine Tool Industry, 1840–1910, The Journal of Economic History, Vol. 23, No. 4, 1963, pp. 414-443.

[22] NIOSH, Criteria for a Recommended Standard: Occupational Exposure to Metalworking Fluids, National Institute for Occupational Safety and Health, 1998.

[23] I.A.Greaves, E.A.Eisen and T.J.Smith, Respiratory Health of Automobile

Workers Exposed to Metal-Working Fluid Aerosols: Respiratory Symptoms, American Journal of Industrial Medicine, Vol. 32, No. 5, 1997, pp. 450-459.
[24] Peter Zelinski, The 400 difference, Modern Machine Shop, 2011.
[25] Peter Zelinski, Toward More Seamless MQL, Modern Machine Shop-2006.
[26] Derek Korn, The Many Ways FORD Benefits from MQL, Modern Machine Shop, Vol. 83, No. 5, 2010, pp. 68-75.
[27] M.H.Tsai, Chi-Neng Cheng and Ming-Chang Shih, Design and Control for the Pneumatic Cylinder Precision Positioning under Vertical Loading, Proceedings of the 21st Annual ASPE Meeting, Vol. 1921, 2006.
[28] News from America, Separating Tramp Oil, Filtration & Separation, Vol. 27, No. 2, 1990, pp. 128, https://doi.org/10.1016/0015-1882(90)80225-A.
[29] Masoud Bozorg Bigdeli, Matteo Fasano, Annalisa Cardellini, Eliodoro Chiavazzo and Pietro Asinari, A Review on the Heat and Mass Transfer Phenomena in Nanofluid Coolants with Special Focus on Automotive Applications, Renewable and Sustainable Energy Reviews, Vol. 60, 2016, pp. 1615-1633, http://dx.doi.org/10.1016/j.rser.2016.03.027.
[30] Edward M.Trent and Paul K.Wright, Metal Cutting, Elsevier, Butterworth-Heinemann, USA, 2000, pp. 311-337.
[31] Z.Tang and S.Li, A Review of Recent Developments of Friction Modifiers for Liquid Lubricants (2007–present), Current Opinion in Solid State and Materials Science, Vol. 18, No. 3, 2014, pp. 119-139, http://dx.doi.org/10.1016/j.cossms.2014.02.002.
[32] Thadathil S.Sreeremya, Asha Krishnan, A.Peer Mohamed, U.S.Hareesh and Swapankumar Ghosh, Synthesis and Characterization of Cerium Oxide based Nanofluids: An Efficient Coolant in Heat Transport Applications, Chemical Engineering Journal, Vol. 255, 2014, pp. 282-289, http://dx.doi.org/10.1016/j.cej.2014.06.061.
[33] Jun Liu, Peng Li, Li Chen, Yang Feng, Wanxia He, Xuehua Yan and Xiaomeng Lu, Superhydrophilic and Underwater Superoleophobic Modified Chitosan-Coated Mesh for Oil/Water Separation, Surface and Coatings Technology, Vol. 307, 2016, pp. 171-176, http://dx.doi.org/10.1016/j.surfcoat.2016.08.052.
[34] Yuanlie Yu, Hua Chen, Yun Liu, Vincent S.J. Craig and Zhiping Lai, Selective Separation of Oil and Water with Mesh Membranes by Capillarity, Advances in Colloid and Interface Science, Vol. 235, 2016, pp. 46-55, http://dx.doi.org/10.1016/j.cis.2016.05.008.
[35] Jian Li, Dianming Li, Weijun Li, Haoyu Li, Houde She and Fei Zha, Facile Fabrication of Underwater Superoleophobic SiO2 Coated Meshes for Separation of Polluted Oils from Corrosive and Hot Water, Separation and Purification Technology, Vol. 168, 2016, pp. 209-214, http://dx.doi.org/10.1016/j.seppur.2016.05.053.
[36] S.D.Supekar, A.F.Clarens, D.A.Stephenson and S.J.Skerlos, Performance of Supercritical Carbon Dioxide Sprays as Coolants and Lubricants in Representative Metalworking Operations, Journal of Materials Processing Technology, Vol. 212, No. 12, 2012, pp. 2652-2658, http://dx.doi.org/10.1016/j.jmatprotec.2012.07.020.

APPENDIX

Table A1.Bill of material and cost estimation

Sl. No.	Description	Material	Type	Quantity	Amount (Rs.)
1.	Coolant tank	Steel	Standard rectangular shaped	1	1000
2.	Pneumatic cylinder	Aluminium	Single acting, bore size 12 mm, stroke 150 mm	2	5000
3.	Supporting blocks	Cast iron	Rectangular shaped	4	300
4.	Fasteners	Steel	Standard M5, M6, M10 hallen bolt and nut	14, 17, 5 pieces each	600
5.	Springs	Steel	Coiled shaped, 2 mm and 5 mm with 10 mm diameter	2 pieces each	200
6.	Guide rods	Steel	Cylindrical shaped rod	2	200
7.	Moving blocks	Cast iron	Rectangular shaped	4	300
8.	Oil tray	Sheet metal	Rectangular shaped block plate	1	500
9.	Angle bracket	Steel	L shaped angle plate	1	200
10.	Supporting rods	Steel	Cylindrical shaped rod	3	100
11.	Clamp plate	Sheet metal	Rectangular shaped plate	1	100
12.	Sponge holder	Sheet metal	Rectangular shaped block	1	100
13.	Sponge pressing block	Sheet metal	Rectangular shaped block	1	100
14.	Solenoid valves	-	Single phase, 110V, 50 hertz	2	4000
15.	Air fitting	Plastic	Compact male connector	4	200
16.	Speed control valve	Plastic	Screw controlled	4	1600
17.	Tee union	Plastic	Branch tee	1	100
18.	Metal fitting	Steel	Thread cut	1	100
19.	Transformer (optional)	-	220V to 110V	1	1000
20.	Electrical switch	-	-	2	500
21.	Tools used	Steel	Hallen key, cutting plier, spanner, screw driver, cutter, etc.	-	1000
22.	Miscellaneous	-	Sponge, welding, drilling, tapping, threading, painting, etc.	-	1000
				TOTAL	**18200**

Table A2.Validation trials by varying dipping time

Sl. No.	**Fa (s)**	**Di (s)**	**Ri (s)**	**Dw (s)**	**TMf (s)**	**Fa (s)**	**Pr (s)**	**Ri (s)**	**TMb (s)**	**Total Time (s)**	**Amount of Oil Separated (ml)**
1.	1.8	6.8	1.8	22.7	1.4	1.5	13.5	1.5	1.4	52.4	33
2.	1.8	6.3	1.8	22.7	1.4	1.5	13.5	1.5	1.4	51.9	32
3.	1.8	5.8	1.8	22.7	1.4	1.5	13.5	1.5	1.4	51.4	31
4.	1.8	5.9	1.8	22.7	1.4	1.5	13.5	1.5	1.4	51.5	30
5.	1.8	6.4	1.8	22.7	1.4	1.5	13.5	1.5	1.4	52	31
6.	1.8	6.2	1.8	22.7	1.4	1.5	13.5	1.5	1.4	51.8	31
7.	1.8	5.8	1.8	22.7	1.4	1.5	13.5	1.5	1.4	51.4	30
8.	1.8	5.5	1.8	22.7	1.4	1.5	13.5	1.5	1.4	51.1	30
9.	1.8	5.2	1.8	22.7	1.4	1.5	13.5	1.5	1.4	50.8	29
10.	1.8	5.4	1.8	22.7	1.4	1.5	13.5	1.5	1.4	51	30
11.	1.8	4.8	1.8	22.7	1.4	1.5	13.5	1.5	1.4	50.4	30
12.	1.8	5.3	1.8	22.7	1.4	1.5	13.5	1.5	1.4	50.9	31

13.	1.8	4.6	1.8	22.7	1.4	1.5	13.5	1.5	1.4	50.2	31
14.	1.8	5.6	1.8	22.7	1.4	1.5	13.5	1.5	1.4	51.2	32
15.	1.8	5.9	1.8	22.7	1.4	1.5	13.5	1.5	1.4	51.5	32
									Average	**51.3**	**30.8**

Table A3.Validation trials by varying dwelling time

Sl. No.	**Fa (s)**	**Di (s)**	**Ri (s)**	**Dw (s)**	**TMf (s)**	**Fa (s)**	**Pr (s)**	**Ri (s)**	**TMb (s)**	**Total Time (s)**	**Amount of Oil Separated (ml)**
1.	1.8	5.4	1.8	21.7	1.4	1.5	13.5	1.5	1.4	50	32
2.	1.8	5.4	1.8	22.2	1.4	1.5	13.5	1.5	1.4	50.5	33
3.	1.8	5.4	1.8	21.9	1.4	1.5	13.5	1.5	1.4	50.2	33
4.	1.8	5.4	1.8	22.5	1.4	1.5	13.5	1.5	1.4	50.8	33
5.	1.8	5.4	1.8	23.1	1.4	1.5	13.5	1.5	1.4	51.4	34
6.	1.8	5.4	1.8	21.2	1.4	1.5	13.5	1.5	1.4	49.5	30
7.	1.8	5.4	1.8	21.6	1.4	1.5	13.5	1.5	1.4	49.9	30
8.	1.8	5.4	1.8	22.8	1.4	1.5	13.5	1.5	1.4	51.1	33
9.	1.8	5.4	1.8	22.7	1.4	1.5	13.5	1.5	1.4	51	33
10.	1.8	5.4	1.8	22.3	1.4	1.5	13.5	1.5	1.4	50.6	32
11.	1.8	5.4	1.8	23.5	1.4	1.5	13.5	1.5	1.4	51.8	34
12.	1.8	5.4	1.8	21.9	1.4	1.5	13.5	1.5	1.4	50.2	32
13.	1.8	5.4	1.8	22.5	1.4	1.5	13.5	1.5	1.4	50.8	33
14.	1.8	5.4	1.8	23.1	1.4	1.5	13.5	1.5	1.4	51.4	30
15.	1.8	5.4	1.8	21.7	1.4	1.5	13.5	1.5	1.4	50	28
									Average	**50.6**	**32**

Table A4.Validation trials by varying pressing time

Sl. No.	**Fa (s)**	**Di (s)**	**Ri (s)**	**Dw (s)**	**TMf (s)**	**Fa (s)**	**Pr (s)**	**Ri (s)**	**TMb (s)**	**Total Time (s)**	**Amount of Oil Separated (ml)**
1.	1.8	5.4	1.8	22.7	1.4	1.5	13.4	1.5	1.4	50.9	28
2.	1.8	5.4	1.8	22.7	1.4	1.5	13.8	1.5	1.4	51.3	29
3.	1.8	5.4	1.8	22.7	1.4	1.5	14.1	1.5	1.4	51.6	30
4.	1.8	5.4	1.8	22.7	1.4	1.5	14.2	1.5	1.4	51.7	30
5.	1.8	5.4	1.8	22.7	1.4	1.5	13.5	1.5	1.4	51	30
6.	1.8	5.4	1.8	22.7	1.4	1.5	13.7	1.5	1.4	51.2	31
7.	1.8	5.4	1.8	22.7	1.4	1.5	13.9	1.5	1.4	51.4	31
8.	1.8	5.4	1.8	22.7	1.4	1.5	14.1	1.5	1.4	51.6	32
9.	1.8	5.4	1.8	22.7	1.4	1.5	13.6	1.5	1.4	51.1	30
10.	1.8	5.4	1.8	22.7	1.4	1.5	13.5	1.5	1.4	51	30
11.	1.8	5.4	1.8	22.7	1.4	1.5	12.8	1.5	1.4	50.3	30
12.	1.8	5.4	1.8	22.7	1.4	1.5	12.7	1.5	1.4	50.2	29
13.	1.8	5.4	1.8	22.7	1.4	1.5	13.5	1.5	1.4	51	30
14.	1.8	5.4	1.8	22.7	1.4	1.5	14.8	1.5	1.4	52.3	32
15.	1.8	5.4	1.8	22.7	1.4	1.5	14.2	1.5	1.4	51.7	31
									Average	**51.2**	**30.2**

Table A5.Validation trials by varying all time intervals

Sl. No.	Fa (s)	Di (s)	Ri (s)	Dw (s)	TMf (s)	Fa (s)	Pr (s)	Ri (s)	TMb (s)	Total Time (s)	Amount of Oil Separated (ml)
1.	1.8	3.9	1.8	20.1	1.4	1.5	12.8	1.5	1.4	46.2	26
2.	1.8	4.5	1.8	22.3	1.4	1.5	12.3	1.5	1.4	48.5	28
3.	1.8	4.2	1.8	21.8	1.4	1.5	12.8	1.5	1.4	48.2	27
4.	1.8	4.8	1.8	21.6	1.4	1.5	13.8	1.5	1.4	49.6	28
5.	1.8	5.3	1.8	22.6	1.4	1.5	13.2	1.5	1.4	50.5	30
6.	1.8	5.8	1.8	20.6	1.4	1.5	13.9	1.5	1.4	49.7	28
7.	1.8	5.3	1.8	21.5	1.4	1.5	14.1	1.5	1.4	50.3	29
8.	1.8	5.5	1.8	22.1	1.4	1.5	14.8	1.5	1.4	51.8	30
9.	1.8	5.9	1.8	21.6	1.4	1.5	14.1	1.5	1.4	51	31
10.	1.8	6.2	1.8	21.4	1.4	1.5	13.8	1.5	1.4	50.8	29
11.	1.8	5.7	1.8	22.6	1.4	1.5	12.8	1.5	1.4	50.5	30
12.	1.8	4.6	1.8	21.9	1.4	1.5	12.5	1.5	1.4	48.4	26
13.	1.8	4.1	1.8	22.5	1.4	1.5	13.8	1.5	1.4	49.8	28
14.	1.8	4.5	1.8	23.1	1.4	1.5	13.2	1.5	1.4	50.2	30
15.	1.8	5.2	1.8	21.7	1.4	1.5	14.1	1.5	1.4	50.4	30
									Average	**49.7**	**28.6**

Table A6.Comparison between separators

Sl. No.	Description	Oil separating accessory	Belt type oil separator
1.	Rate of oil separation	Moderate	Very slow
2.	Oil sticking type	To the sponge	To the belt
3.	Area of oil sucking	Sponge covered more space	Belt covers very less space
4.	Type of oil separated	Almost all types	Many types will not stick to the belt
5.	Operating cost	Low, hence pneumatic cylinders used	High, need electric power supply
6.	Maintenance cost	Very low	High
7.	Cost of separator	Low	Expensive
8.	Efficiency for an hour	94.58 % of oil separated	83.33 % of oil separated
9.	Affected source	No source affects the efficiency	Efficiency affected by debris
10.	Mounting type	Mounting on top of machining centers possible	Not possible
11.	Oil absorbing capacity	Effective	Not effective
12.	Installation type	Easy	Difficult
13.	Weight	Light	Heavy